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ALLEGANY BALLISTICS LABORATORY
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FILAMENT WOUND ROCKET MOTOR CHAMBERS

FINAL REPORT

SEPTEMBER 1976

PRIME CONTRACT NAS7-100
SUBCONTRACT NO. 954136

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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ABSTRACT

This report is the final report under Contract No. 954136 to the Jet Propulsion Laboratory (JPL) for the design, analysis, fabrication and testing of a Kevlar-49/HBRF-55A Filament Wound Chamber.

The chamber was fabricated and successfully tested to 80% of the design burst pressure. Results of the data reduction and analysis from the hydrotest indicate that the chamber design and fabrication techniques used for the chamber were adequate and the chamber should perform adequately in a static test.

The chamber has been shipped to JPL for insulation and subsequent propellant loading and static firing.

A. INTRODUCTION

The original technical objectives of the Filament Wound Chamber Program were to design, analytically characterize the structural performance and integrity of a Kevlar-49/HBRF-55A filament wound rocket motor chamber, and to fabricate and test three chambers. One chamber was to be burst tested and the remaining two chambers were to be delivered to JPL for insulation, propellant loading and static firing.

The program start date was January 28, 1975, and was to end on December 9, 1975. The first 4 months of the program were devoted to the design and analysis task of the program. A design report [1] was issued which covered the details of this phase of the program. Other tasks in the program were: (1) Fabrication and (2) Testing and Demonstration. The Fabrication task includes the design and fabrication of the tooling, preparation of chamber winding procedures, and fabrication of the chamber and its components. The Testing and Documentation task includes the design and fabrication of the test tooling, preparation of the test plan, chamber testing, and reporting.

Due to financial problems during the program, the program was modified after the fabrication of the first chamber. Chamber No. 1 was originally scheduled to be hydroburst; however, in August 1975, JPL directed that this chamber would be tested to 80% of burst (742 psig) and subsequently delivered to JPL for insulation, propellant loading and static testing.

This report will cover the work performed since the design report.

B. CHAMBER DESIGN

The chamber design and analysis were covered in detail in Reference 1. In summary, the chamber is a filament wound Kevlar-49/HBRF-55A epoxy composite structure with aluminum pole pieces (bosses) and S-901 and S-34-901 fiberglass epoxy skirts. The specific design requirements for the chamber are given in Table I and a design description of the chamber final design is given in Figure 1 and Table II. A comparison between the JPL requirements and chamber design, as well as the actual (as-fabricated) chamber dimensions, are also given in Table I.

C. FABRICATION

C.1 MANDREL TOOLING AND MANDREL PREPARATION

The JPL filament wound chamber was fabricated on a plaster mandrel. The plaster mandrel tooling consisted of a steel shaft, wooden supports, support stand and templates. The tooling for the plaster mandrel was manufactured in accordance with drawings 60309J63001 and 60309J63002.

The plaster mandrel tooling was assembled and burlap was placed over the mandrel support and treated with plaster. The rought screeding template was then positioned to allow for a thin final coat of plaster. A mixture of pottery and high strength plaster was applied to the burlap until the plaster met the contour of the rough template. The rough template was then replaced with the finished contoured template and the final coat of plaster was applied. The mandrel was cured in an oven at 125° ± 15°F for approximately 80 hours. Small vent holes were drilled through

TABLE I

CHAMBER DESIGN REQUIREMENTS WITH DESIGN AND ACTUAL DIMENSIONS

Item	Requirements		Actual
	JPL	Final Design	
Diameter (in.)	50.0	50.0 Cylinder 50.040 Skirt	50.047 max.
Length (in.)	----	47.66	47.710
Length to Diameter Ratio	1	0.953	0.953
Internal Volume (in.^{3})	73,140	73,071	72,935
Openings, Diameter Nozzle Boss (in.)	14 to 17	15.500	15.496
Igniter Boss (in.)	3 to 14	7.210	7.209
Skirts (number) Edge-to-Edge Distance (in.)	2 ----	2 24.61	2 24.62
Weight (lb_m)	74 max.	72	82
Firing Pressure (average psig)	600	----	----
Proof Pressure (psig)	742	742	742 passed

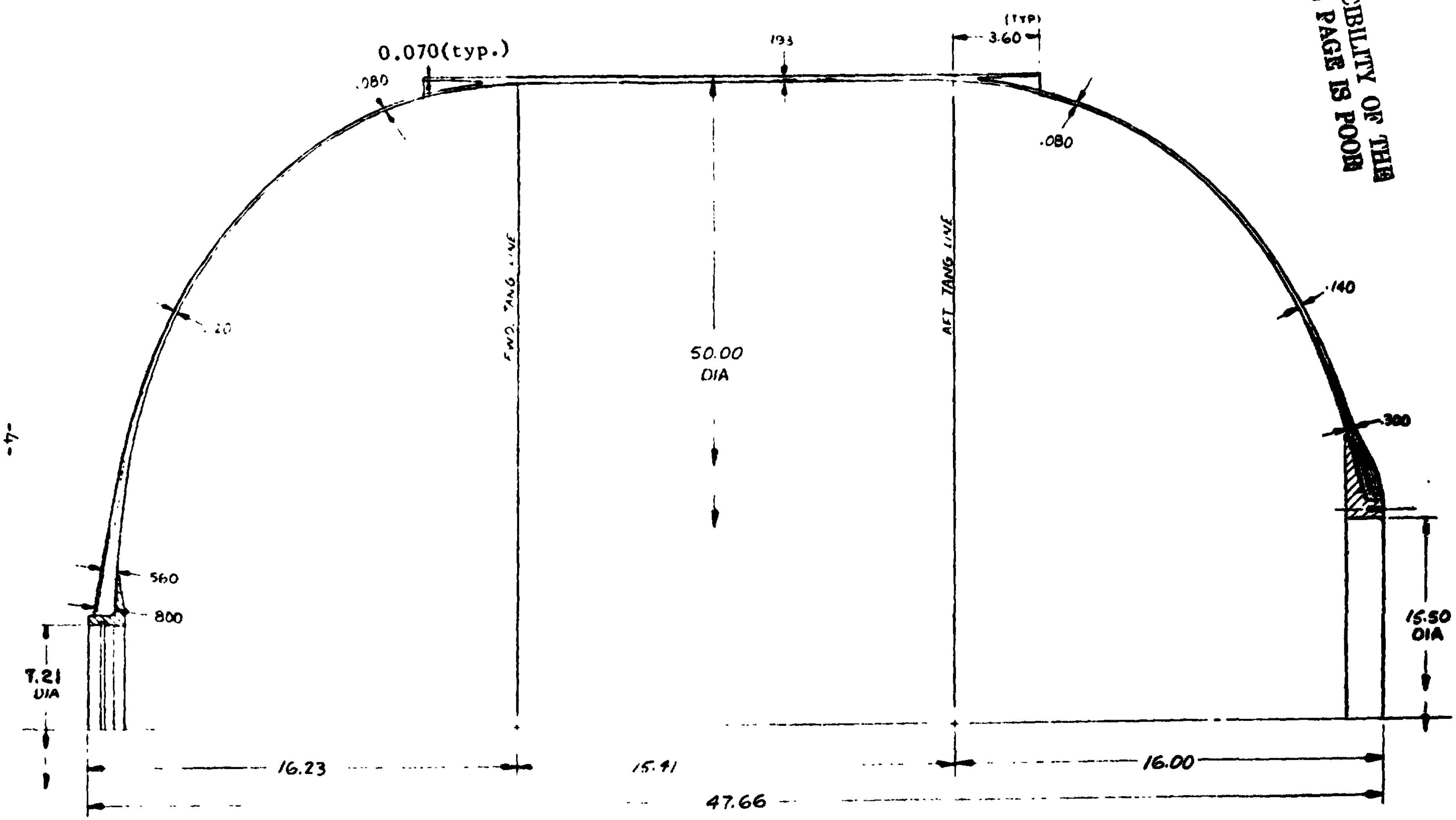


Figure 1. Chamber Design

TABLE II

J.P.L. FILAMENT-WOUND CHAMBER DESIGN DESCRIPTION

Construction	Deviated Winding,
Fiber	Chamber - Kevlar-49-III (4560 denier - 4 end roving)
	Skirts - S-901 Fiberglass and S-34-901 Fiberglass Cloth
Resin	HBRF-55A
Nominal Diameter	127 cm (50 in.)
Overall Length	121.056 cm (47.66 in.)
Aft Polar Opening	39.37 cm (15.5 in.)
Forward Polar Opening	19.609 cm (7.21 in.)
Helical Bandwidth	2.616 cm (1.03 in.)
Hoop Bandwidth	2.126 cm (0.837 in.)
Winding Pattern	XO●X●XO●XO●
Chamber Volume	Aft Dome = 353.65 ℓ (21,577 in.^{3}) Forward Dome = 355.70 ℓ (21,702 in.^{3}) Cylinder = 488.29 ℓ (29,792 in.^{3}) Total Volume = 1197.64 ℓ (73,071 in.^{3})
Chamber Weight	Bosses = 4.75 Kg (10.48 lb) Pressure Vessel = 25.19 Kg (55.55 lb) Skirts = 2.50 Kg (5.50 lb) Total Weight = 32.44 Kg (71.53 lb)

PV/W = 0.95 x 10^6 in.

the plaster shell to allow residual moisture to escape from the winding during cure. A sheet of uncured SBR-silica rubber (0.030 in. thick) was applied over the mandrel and cured at 300° ± 15°F for 4 ± ½ hr. After the rubber was cured, teflon tape was applied to the winding surface to complete the mandrel fabrication.

Pole pieces were machined in accordance with drawings 60309S20002 and 60309S20003 and dimensionally inspected. The face of the pole pieces were degreased, grit blasted and degreased again, at which time the cured SBR-silica rubber shear pad was bonded in place. This completed the mandrel assembly for winding the chamber as given in drawing 60309J63001.

Mandrels for winding the skirts for the chamber were fabricated in accordance with drawing 60309J63004.

C.2 CHAMBER WINDING

Prior to winding, the mandrel was placed into the winding machine for machine programming. The plaster mandrel was marked with the designed winding path and the fiber delivery head was positioned to deliver the filaments on the prescribed path. During this process the winding cam was marked, cut and adjusted for accuracy.

Prior to winding the Kevlar-49 roving was dried by placing it in an oven at 250 ± 10°F for 24 hours. The roving was removed from the oven and placed in preheated compartments on the winding machine and maintained at 140 ± 15°F during the winding.

The materials used in the winding of the chamber are given in Table III. The Kevlar-49 roving was tested prior to winding using the impregnated

TABLE III

CHAMBER MATERIALS

Item	Material Description	Purchase Lot No./Description
Kevlar-49 Roving	Kevlar-49, 4-end roving (4560 denier), Fiber Lot #90	P.O. No. 03002
Winding Resin	Epon 826 Araldite RD-2 Tonox 6040	P.O. No. 03009 P.O. No. 03011 P.O. No. 03010
Pole Piece Material	1.5 in. thick x 25 in. square, 7075-T73 Aluminum Plate	P.O. No. 03007
Kevlar-49 Reinforcement Cloth	Style 120 - Kevlar-49 Cloth	P.O. No. 03012
S-901 Fiberglass Roving	S-901, 12-end roving*	H.S.-CP-112
S-Glass Cloth for Skirts	S-34-901 Fiberglass Cloth*	H.S.-CP-139
S-Glass Cloth for Dome Reinforcement	S-116 Fiberglass Cloth*	Vendor Specs.
Strip Liner	SBR-Silica, 0.032 in.* thick	WS-8940

*Material on hand; purchase to given specifications.

strand test (ASTM D-2343-67). Results of the tests are given in Table IV. Note that the strand strength at a fiber volume of approximately 55% is 501,000 psi which is what was expected based on previous evaluation of Kevlar-49 fiber.

The chamber was wound during the last week in July 1975 and very few fabrication problems were experienced during the winding. The chamber was wound in accordance with drawings 60309S20001 and 60309S20004. One problem area did result, however, at the forward pole piece. Due to the low winding angle in the forward dome, an excessive amount of fiber bridging was experienced. Although some bridging was expected, the amount of fiber bridging that occurred during the winding resulted in extra HBRF-55A epoxy resin to fill the voids left by the bridged fibers. Table V presents the sequence used in the chamber fabrication. The winding tension used during the fabrication process was 2 ± ½ pounds per roving.

After the chamber and skirt winding was completed, the unit was moved to a gas fired oven and cured, while rotating, at 210 ± 15°F for 7 ± ½ hours at 250 ± 15°F. The cure temperature was monitored by thermocouples attached to the skirt mandrel and recorded and controlled by instrumentation outside of the oven.

After chamber cure, the plaster mandrel was removed by pulling the steel winding shaft and the wooden support frames. The plaster was then chipped away using a chisel. During this operation, the rubber liner was penetrated in four locations by the chisel, and the interior of the chamber was slightly damaged. These damaged areas were repaired with S-116 style

TABLE IV

STRAND DATA FOR KEVLAR-49/HBRF-55A (FIBER LOT NO. 90)

Resin Content (% Wt.)	Fiber Volume (% Vol.)	Break Load (lb)	Strand Tensile Strength (psi)	Strand Tensile Modulus (10^6 psi)
0	100	168* (CV = 3.8%)	306,200* (CV = 3.8%)	19.2*
29.5	66	190 (CV = 6.6%)	350,740 (CV = 6.6%)	17.8 (CV = 5.4%)
47.2	49	255 (CV = 5.6%)	469,840 (CV = 5.6%)	17.9 (CV = 3.2%)
54.5	41	272 (CV = 2.9%)	501,130 (CV = 2.9%)	17.9 (CV = 2.2%)

*Data obtained by JPL

TABLE V

JPL FILAMENT CHAMBER WINDING SEQUENCE

Step	Description
1	Wind first helical layer with Kevlar-49/HBRF-55A.
2	Wind one and one-half (1½) hoop layers with Kevlar-49/HBRF-55A.
3	Lay up S-116 fiberglass cloth wafer in dome-cylinder region.
4	Lay up Kevlar-49 Type 120 cloth wafers in forward and aft domes.
5	Wind second helical layer with Kevlar-49/HBRF-55A.
6	Wind 1/2 hoop layer with Kevlar-49/HBRF-55A.
7	Lay up Kevlar-49 Type 120 cloth wafers in domes and Kevlar-49 cloth strips in dome/cylinder areas.
8	Wind third helical layer with Kevlar-49/HBRF-55A.
9	Wind one and one-half (1½) hoop layers with Kevlar-49/HBRF-55A.
10	Lay up Kevlar-49 Type 120 cloth wafer in domes and cloth in dome/cylinder areas.
11	Wind fourth helical layer with Kevlar-49/HBRF-55A.
12	Wind one and one-half (1½) hoop layers with Kevlar-49/HBRF-55A.
13	Assemble skirt tooling.
14	Lay up fiberglass skirts with S-116 cloth and alternate layers of S-34-901 fiberglass cloth and S-901 hoop windings.

fiberglass fabric and/or EA-953 epoxy resin. Since this chamber was originally scheduled to be burst tested, these repairs were not considered to be serious since they have been used successfully on previous filament wound chambers.

The chamber's final dimensions are presented in Table I. After removal of the plaster mandrel, the chamber did experience a spring-out of approximately 0.3 in. This is not surprising since Kevlar-49 fiber possesses a negative thermal coefficient of the expansion and the winding angle of this chamber is low. Similar response has been noted by JPL in their work with graphite/epoxy motor cases. Experience with thin-walled fiberglass chambers indicates that after mandrel removal the chambers usually spring-in; however, this material possesses a high coefficient of thermal expansion compared to Kevlar and graphite.

The chamber was approximately ten (10) pounds heavier than the chamber design prediction. The total ten pound weight difference is not completely explainable at this time. It is anticipated that most of the added weight is due to the resin required to fill the voids resulting from bridging in the forward dome. Also the chamber skirts were thicker than design and the interior of the chamber contained additional resin and cloth due to the patches. A full explanation of the weight difference cannot be made until after the case is burst tested. It is anticipated that the weight could be reduced on subsequent chambers by a slight modification of the winding pattern, by winding with a higher fiber tension and by additional blotting of the chamber surface to remove the excess resin. Also, the pole pieces could be shaved in the non-critically stressed areas to further lighten the chamber.

D. HYDROTEST

D.1 TEST PLAN AND INSTRUMENTATION

The filament wound chamber was tested at the Hercules/ABL Structures Laboratory. Test tooling for conducting the test consisted of a forward closure, aft closure and piston assembly, and associated hardware necessary for supporting the chamber in the test fixture. The tooling was fabricated in accordance with drawing 60309J62001. The chamber was tested with the forward end down and the thrust load was simulated with the piston in the aft end of the chamber. The test plan for the hydrotest is included in Appendix A, and the chamber instrumentation plan is given in drawing 60309J62002.

Since the chamber did not contain an insulator, the interior of the chamber was lined with "Spraylat" which is a lining material which was used previously on Sprint chambers during hydrotest. The Spraylat acts as a liner and prevents leakage through the composite case wall.

D.2 HYDROTEST RESULTS

The chamber was tested on August 14, 1975. The original test plan called for the chamber to be subjected to a low pressure leak test, a 50% of proof pressure test, a proof test, and a hydroburst. The low pressure leak and 50% of proof pressure tests were successfully accomplished with full instrumentation. During the change-in-volume measurements following the 50% of proof pressure test, a leak was detected in the aft dome of the chamber. The test was aborted at that time in order to prevent damage to the chamber. The chamber was removed from the test stand and inspected.

It was found that the Spraylat had become separated from the aft pole piece and water had gotten under the Spraylat. The chamber was dried, the Spraylat was bonded in place, and the chamber interior was coated with two additional layers of Spraylat. The chamber was then set up in the test stand for a retest.

At the direction of JPL, the test plan was modified to eliminate the hydroburst cycle and the chamber was hydroproofed on August 27, 1975.

The chamber was proof tested to 742 psig, 80% of the designed burst pressure. Pressure versus time, pressure versus strain, and acoustic emissions data that were recorded during the test are given in Appendix B. The actual proof procedure followed the original test plan. The pressurization rate occurred as planned except for a reduction to 4.4 psi/second starting at a chamber pressure of 710 psig. The proof pressure of 742 psig was held for 60 seconds.

Strain gages were located on the chamber in areas where the finite element analysis predicted high stresses. The purpose of the strain gages was to correlate the fabrication procedure with the chamber design. The strain gage locations are given in Figure 2. All of the strain gages gave results which appeared to be consistent with the predicted results except for the gage located at the forward tangent point. This strain was much higher than expected and higher than the adjacent gage located in the same orientation. None of the adjacent gages indicated strains of this magnitude and, therefore this gage was not included in the results. In addition to the strain data, the chamber skirt-to-skirt growth at proof conditions were monitored with a linear potentiometer and indicated a 0.26 inch growth

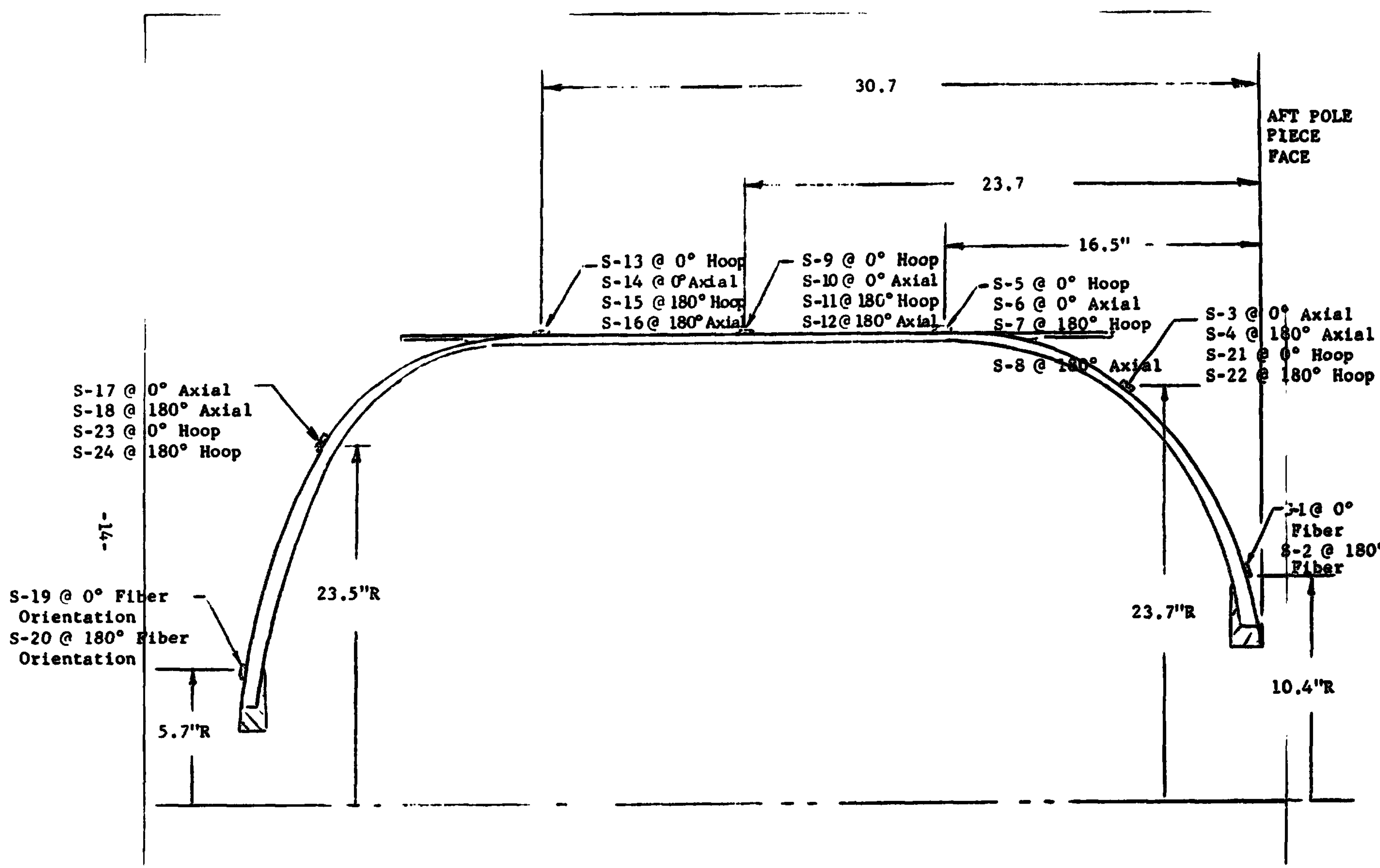


Figure 2. Location of Strain Gages for JPL Chamber 001 Hydrotest

compared to the 0.22 inch predicted.

Volumetric growth of the chamber was measured by decanting the water from the pressurized chamber into a calibrated cylinder and in turn measuring the pressure after each filling of the cylinder. This data is presented in Figure 3 for proof pressure and leak test conditions. The initial chamber volume of 72,697 in.^{3} is in good agreement with the 73,071 in.^{3} predicted during the analysis. The measured volume is slightly less due to the Spraylat liner used to prevent leakage during the hydrotest.

E. DISCUSSION OF RESULTS

A comparison of the measured and predicted strains for the JPL filament wound chamber is given in Table VI. The actual strains reported are the average of the gages located at 0° and 180° around the chamber circumference at the particular location indicated in the table. Note the excellent agreement between the measured and predicted strains at all locations.

The strains measured at the forward and aft tangent points are lower than predicted due to the fiberglass and Kevlar-49 fabric that were added to the chamber design in order to lower the shear stresses in the skirt/dome joint (see Reference 1).

The volumetric growth of the chamber given in Figure 3 was not linear and approximately 4.0% above the predicted amount at 742 psig proof. At the average pressure of 650 psig, the volumetric growth is 2675 in.^{3} or 3.7% above the predicted. The non-linear behavior of the volumetric growth

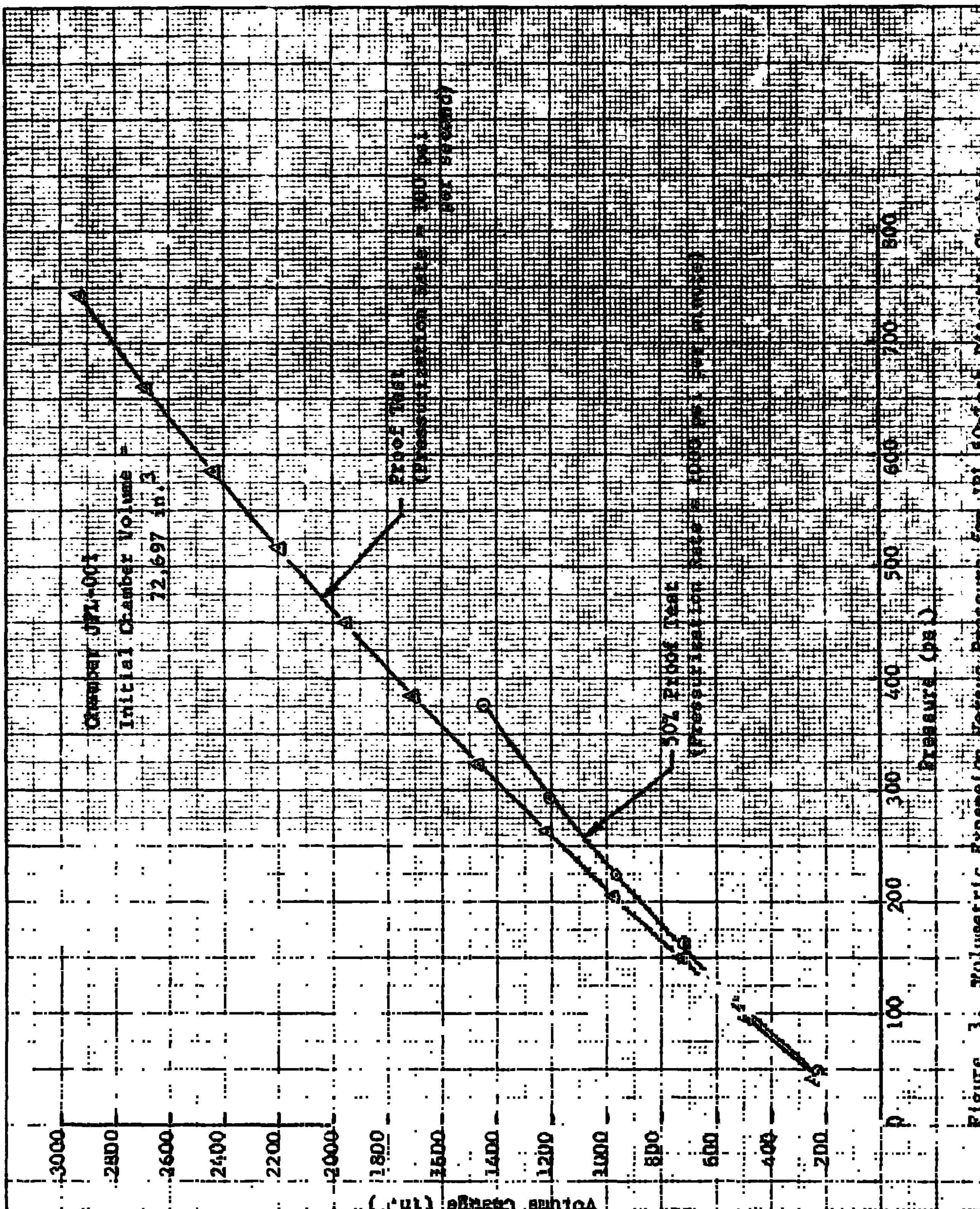


Figure 3. Volumetric Expansion Versus Pressure for JPL 50-Inch Diameter Chamber
Chamber JPL 001

TABLE VI

RESULTS OF JPL CHAMBER #1 PROOF TEST

Gage No.	Location	Actual Strain (%)	Predicted Strain (%)
	Cylindrical Section		
S5	16.5" from aft pole piece face @ 0^{o}H	0.94	0.98
S6	16.5" -do- @ 0^{o}A	1.16*	1.16
S7	16.5" -do- @ 180^{o}H	0.81	0.98
S8	16.5" -do- @ 180^{o}A	1.00	1.16
S9	23.7" -do- @ 0^{o}H	1.41	1.39
S10	23.7" -do- @ 0^{o}A	1.14*	1.09
S11	23.7" -do- @ 180^{o}H	1.38	1.39
S12	23.7 -do- @ 180^{o}A	1.26	1.09
S13	30.7 -do- @ 0^{o}H	0.98	1.00
S14	30.7 -do- @ 0^{o}A	1.22	1.26
S15	30.7 -do- @ 180^{o}H	0.92	1.00
S16	30.7 -do- @ 180^{o}A	**	1.26
	Forward Dome		
S17	23.5" R @ 0^{o}A	1.34	1.29
S18	23.5" R @ 180^{o}A	1.34	1.29
S23	23.5" R @ 0^{o} H	0.62	0.69
S24	23.5" R @ 180^{o}H	0.58	0.69
S19	5.7" R @ 0^{o} Fiber	1.08	1.08
S20	5.7" R @ 180^{o} Fiber	1.08	1.08

* Data Extrapolated

** Data Questionable

TABLE VI (Cont'd)

Gage No.	Location	Actual Strain (%)	Predicted Strain (%)
	Aft Dome		
S3	23.7" R @ 0°A	1.39	1.25
S4	23.7" R @ 180°A	1.39	1.25
S21	23.7" R @ 0° H	0.78	0.88
S22	23.7" R @ 180° H	0.52	0.88
S1	10.4" R @ 0° Fiber	1.16	1.12
S2	10.4" R @ 180° Fiber	1.24	1.12
LP2	Skirt-to-Skirt	0.26 in.	0.22 in.*

*Did not account for rotation of skirt. LP contacted block 1.5 in. from chamber surface.

versus pressure curve is consistent with data observed on previous chambers. Theoretically the chamber volumetric growth should be linear because the chamber is designed as a geodesic oveloid. The reason for the non-linear behavior is that during the initial phases of pressurization, the domes, which during fabrication are not exactly configured as ideal geodesic oveloids, seek the ideal configuration which is their minimum energy state. This causes them to grow outward or possibly inward, depending on which side of the minimum energy level at which they are maintained. Note that data from the 50% proof pressurization is more non-linear than the proof test. Once the minimum energy state is approached, the response is more linear. Note that the proof test response is really bilinear. The bilinearity is probably due to a local yieldir and resin crazing phenomena in the composite.

Chamber coordinates were determined in Reference 2 using the strain and volumetric growth data and appear to be as accurate as any measurements that can be made directly to the chamber interior.

F. CONCLUSIONS

Based on results of the chamber tests, it is concluded that the JPL Filament Wound Chamber design and fabrication techniques used to fabricate the chamber were adequate. This was verified by the excellent correlation between the predicted and actual strain and deflection measurements. The proof test was successful in demonstrating that the chamber could withstand a pressure level of 80% of burst for a 60-second hold period, and the test was also successful in obtaining good data for future chamber analysis.

As predicted by the analysis, the lowest margins of safety occur in the forwa.d dome. However, based on the measured strain data, the chamber should achieve the 928 psig design burst pressure level.

The chamber was packaged and shipped to JPL for insulation and subsequent propellant loading and static firing.

G. REFERENCES

[1] Vicario, A. A., "Filament Wound Rocket Motor Chambers - Final Design Report," Report No. AO-8251-130-01-005, Hercules Incorporated, Cumberland, Maryland, unde. JPL Contract 954136, May 1975.

[2] Jensen, W. M., "Hydrotest Proof of the JPL Advanced Propulsion Module Chamber," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, November 1975.

APPENDIX A

TEST PLAN FOR JPL 50-INCH DIAMETER CHAMBER

H E R C U L E S   I N C O R P O R A T E D
Allegany Ballistics Laboratory
Cumberland, Maryland

July 31, 1975

(Revised: August 12, 1975)

TP-JPL-1001
Revision: 1

TEST PLAN

JPL 50-IN. DIAMETER CHAMBER

HYDROTEST AND BURST TEST

Test Engineering

Product Engineering

Test Operations

Safety

1.0 This test plan governs the proof and burst testing of the JPL 50-in. diameter chamber.

2.0 Test Control

2.1 This test plan defines the objectives, test arrangement, instrumentation requirements, photographic requirements, data recording, and reduction for the subject test.

2.2 Any changes to this test plan which affect the object of the test shall be made by, "Testing Change Order"

3.0 Test Objective

3.1 To verify the design and fabrication techniques and to establish the integrity and design margin of the JPL 50-in. diameter chamber by use of strain gages and linear potentiometers.

3.2 The use of acoustic emission (AE) is to set up a procedure to technically evaluate the structural capability of future rocket motor chambers by relating the events, their rate and summation to proof and burst conditions.

3.3 To obtain volumetric growth vs. pressure to verify the design predictions.

4.0 Applicable Documents

Drawings

60309J62001	JPL 50-In. Dia. Chamber Hydrostatic Test Assembly
60309J62002	JPL 50-In. Dia. Chamber Hydrostatic Test Instrumentation

Publications

GOP 1-74-01	Procedure for Operation of Hydrotest Control System
GOP 1-74-07	Structures Laboratory Operation

HXD 1-441	Procedure for Operation of Data Acquisition System
HXD 1-2073	Installation of Wire Strain Gages on Spiralloy

5.0 Safety

5.1 All safety precautions and practices established in the General Operating Procedures for the area in which this operation is performed shall be observed.

NOTE: THIS OPERATION SHALL BE BROUGHT TO A SAFE, ORDERLY STOP AND TESTING SUPERVISION NOTIFIED IF THERE IS ANY UNUSUAL EVENT WHICH COULD AFFECT SAFETY OR THE QUALITY OR COST OF THE PRODUCT.

6.0 Instrumentation and Assembly

6.1 The chamber will be instrumented with twenty-four (24) PA-7 strain gages in accordance with drawing 60309J62002 and HXD 1-2073.

6.2 Assemble the forward closure and install the closure in accordance with drawing 60309J62001.

6.4 Install Lp 1 per drawing 60390J62002.

6.5 Install the test hardware on the lower and upper platens per drawing 60390J62001.

6.6 Roll the lower platen out and install the chamber pressurization line through the hole in the center of the platen.

6.7 Install the tierod and aft lifting bracket and raise the chamber to the vertical position. Lower the chamber to a convenient location and connect the pressurization line.

6.8 Carefully lower the chamber into the support ring. Align the fwd closure retaining bar with Lp 1.

6.9 Conduct a water weight determination in accordance with the following steps.

6.9.1 Assemble the 5000-lb. load cell on the bay crane. Secure the load cell to a permanent bay structure and exercise the load cell three (3) times to 3000 lbs.

6.9.2 Install the load cell on the tierod and raise the chamber approximately 1 inch above the support ring.

6.9.3 Connect the water fill line and zero the load cell.

6.9.4 Fill the chamber with water to the O-ring groove in the aft adapter. Record the water weight and water temperature. Calculate the total water volume.

6.9.5 Carefully lower the chamber into the support ring. Measure the water level on the aft adapter.

6.9.6 Remove the aft lifting bracket and tierod. Measure the water level on the aft adapter as in Step 6.9.5. Calculate the volume change caused by the tierod and add this volume to the total volume.

6.9.7 Drain enough water from the chamber to permit installation of the aft closure and piston.

6.10 Install the aft closure and pis[illegible] accordance with Dwg. 60309J62001.

6.11 Install Lp 2 brackets and locate the Lp stop block. Bond the block in place with C7 adhesive and cure at room temperature for a minimum of 6 hours.

6.12 Roll the lower platen into the test stand. Verify the piston and piston stop are aligned.

6.13 Install chamber pressure transducers P1 and P2. Install the bleed line.

6.14 Prepare and test the following pressurization programs:

A. 50% Proof - Pressurize the chamber to 370 ± 10 psig at a rate of 1000 ± 10 psig per minute. Hold 50% proof pressure for 90 + 5, - 0 seconds and release.

B. Proof - Pressurize the chamber to $742\ ^{+20}_{-0}$ psig at a rate of 1000 ± 10 psig per minute. Hold proof pressure for 30 seconds and release.

C. Burst - Pressurize the chamber at a rate of 100 psig per second until failure.

6.15 Install acoustic emission sensors AE 1 and 2 on the forward dome and AE 3 and 4 on the aft dome per drawing 60390J62002. Connect and identify the AE sensors.

6.16 Connect and identify all instrumentation. Prepare the recording system per Table I and HXD 1-441.

6.17 Connect the pressurization system and fill the chamber with water. Verify all air has been evacuated from the chamber by permitting the water to flow until it is bubble free.

6.18 Start the recording system and apply water line pressure (100 psi) to the chamber. Shut off the water supply and verify all instrumentation is recording and no leaks are visible. Reduce chamber pressure to zero psi.

6.19 Prepare and install movie cameras per Figure 1.

6.20 Take pre-test black and white still photographs of the test arrangement (plant photographer).

7.0 Test Operations

7.1 Balance and calibrate all instrumentation.

7.2 Verify the 50% proof pressurization program, step 6.13,A, is ready.

7.3 Conduct the 50% proof test per GOP 1-74-07.

7.3.1 Depressurize by bleeding the water into a graduated vessel and measure the water volume required to pressurize the chamber.

7.4 Following the test, conduct a visual inspection for anomalies.

7.5 Identify the digital tape and oscillograph records.

7.6 Prepare the recording system and the pressurization system for the proof test.

7.7 Balance and calibrate all instrumentation.

7.8 Verify the proof pressurization program, step 6.13,B, is ready.

7.9 Conduct the proof test per GOP 1-74-07.

7.9.1 Depressurize by bleeding the water into a graduated vessel and measure the water volume required to pressurize the chamber.

NOTE: START CAMERAS WITH MASTER START.

7.10 Following the test, inspect the chamber.

7.11 Identify the digital tape and oscillograph records.

7.12 Prepare the recording system per Table II and the pressurization system per step 6.13,C.

7.13 Remove the acoustic emission sensors AE 3 and 4 from the chamber.

7.14 Balance and calibrate all instrumentation.

7.15 Verify the burst pressurization program, step 6.13,C, is ready.

7.16 Conduct the burst test per GOP 1-74-07.

NOTE: START CAMERAS WITH MASTER START.

7.17 Identify the digital tape and oscillograph records.

7.18 Take post-test black and white still photographs (plant photographer).

8.0 Photographic

8.1 Two (2) copies B&W, 8 x 10, still photographs are required of each exposure.

8.2 Movie film will be processed at the direction of Product Engineering representative.

9.0 Data Processing

9.1 Structures Laboratory

9.1.1 The digital tapes, with a copy of the Test Data Acquisition Sheet will be delivered to Computations as soon as possible after the test.

9.2 Computations

9.2.1 The following data will be listed on engineering printouts at the specified sampling rates for each test. Three (3) copies of the engineering printouts are required.

a. P1, P2, P1 P2 average - psig

b. S1 through S24 - percent

c. Lp 1 and Lp 2 - inches

9.2.2 Sampling rates will be as follows:

a. 50% proof - 30 samples per second

b. Proof - 30 samples per second

c. Burst - 30 samples per second

NOTE: TEST DURATION WILL BE ESTABLISHED FROM OSCILLOGRAPH RECORDS.

9.2.3 Data graphs of each recorded channel will be required for each test.

a. Pressure vs. time

b. Strain vs. pressure

c. Deflection vs. pressure

d. AE vs. pressure

e. Volume growth vs. pressure

TABLE I

PROOF TEST

Gage Location No.	Location	Max. Expected Value	Calib-ration	Recording	Figure
P1	Chamber Pressure	752 psig	+4	D30, Osc.	Dwg. 60390J62002
P2	Chamber Pressure	752 psig	+4		
S1 S2	Aft Dome 10.4R @ 0° F.O. Aft Dome 10.4R @ 180° F.O.	1.5%	±1		
S3 S4	Aft Dome 23.7R @ 0° (A) Aft Dome 23.7R @ 180° (A)				
S5 S6	Cyl. Sect. 16.5R @ 0°(H) Cyl. Sect. 16.5R @ 0°(A)				
S7 S8	Cyl. Sect. 16.5R @180°(H) Cyl. Sect. 16.5R @180°(A)				
S9 S10	Cyl. Sect. 23.7R @ 0°(H) Cyl. Sect. 23.7R @ 0°(A)				
S11 S12	Cyl. Sect. 23.7R @180°(H) Cyl. Sect. 23.7R @180°(A)				
S13 S14	Cyl. Sect. 30.7R @ 0°(H) Cyl. Sect. 30.7R @ 0°(A)				
S15 S16	Cyl. Sect. 30.7R @180°(H) Cyl. Sect. 30.7R @180°(A)				
S17 S18	Fwd. Dome 23.5R @ 0°(A) Fwd. Dome 23.5R @180°(A)				
S19 S20	Fwd. Dome 5.7R @ 0°F.O. Fwd. Dome 5.7R @180°F.O.				
S21 S22	Aft Dome 23.7R @ 0°(H) Aft Dome 23.7R @180°(H)				
S23 S24	Fwd. Dome 23.5R @ 0°(H) Fwd. Dome 23.5R @180°(H)				
Lp 1 Lp 2	Fwd. Adapter Deflection Skirt to Skirt Growth	0.5" 1.0"	±4 ±4		
AE 1 AE 2	Fwd. Dome @ 0° Fwd. Dome @ 180°				
AE 3 AE 4	Aft Dome @ 0° Aft Dome @ 180°				

Oscillograph speed = 0.5 inch per second.

TABLE II

BURST TEST

Gage Location No.	Location	Max. Expected Value	Calib-ration	Recording	Figure
P1	Chamber Pressure	930 psig	+4	D30, Osc.	Dwg. 60390J6200:
P2	Chamber Pressure	930 psig	+4		
S1 S2	Aft Dome 10.4R @ 0° F.O. Aft Dome 10.4R @ 180° F.O.	3.0%	±1		
S3 S4	Aft Dome 23.7R @ 0° (A) Aft Dome 23.7R @ 180° (A)				
S5 S6	Cyl. Sect. 16.5R @ 0°(H) Cyl. Sect. 16.5R @ 0°(A)				
S7 S8	Cyl. Sect. 16.5R @180°(H) Cyl. Sect. 16.5R @180°(A)				
S9 S10	Cyl. Sect. 23.7R @ 0°(H) Cyl. Sect. 23.7R @ 0°(A)				
S11 S12	Cyl. Sect. 23.7R @180°(H) Cyl. Sect. 23.7R @180°(A)				
S13 S14	Cyl. Sect. 30.7R @ 0°(H) Cyl. Sect. 30.7R @ 0°(A)				
S15 S16	Cyl. Sect. 30.7R @180°(H) Cyl. Sect. 30.7R @180°(A)				
S17 S18	Fwd. Dome 23.5R @ 0°(A) Fwd. Dome 23.5R @180°(A)				
S19 S20	Fwd. Dome 5.7R @ 0°F.O. Fwd. Dome 5.7R @180°F.O.				
S21 S22	Aft Dome 23.7R @ 0°(H) Aft Dome 23.7R @180°(H)				
S23 S24	Fwd. Dome 23.5R @ 0°(H) Fwd. Dome 23.5R @180°(H)				
Lp 1 Lp 2	Fwd. Adapter Deflection Skirt to Skirt Growth	0.6" 1.0"	±4		
AE1 AE2	Fwd Dome @ 0° Fwd Dome @ 180°				

Oscillograph Speed = 0.5 inch per second.

STATIC TESTING PHOTOGRAPHIC COVERAGE

Project 50-In. Chamber Proof & Burst Test Engineer ______

Motor Design 50-In. JPL Chamber Loading No. ______ S/N ______

LOCATION	MAKE	SPEED	FILM	TIME COVERAGE
1	Fastax	See Note	B&W	See Note
2	Fastax	See Note	B&W	See Note
3	Fastax	See Note	B&W	See Note
4				
5				

NOTE: Proof test 200 fps for 80 seconds.
Burst test 1000 fps for 16 seconds.

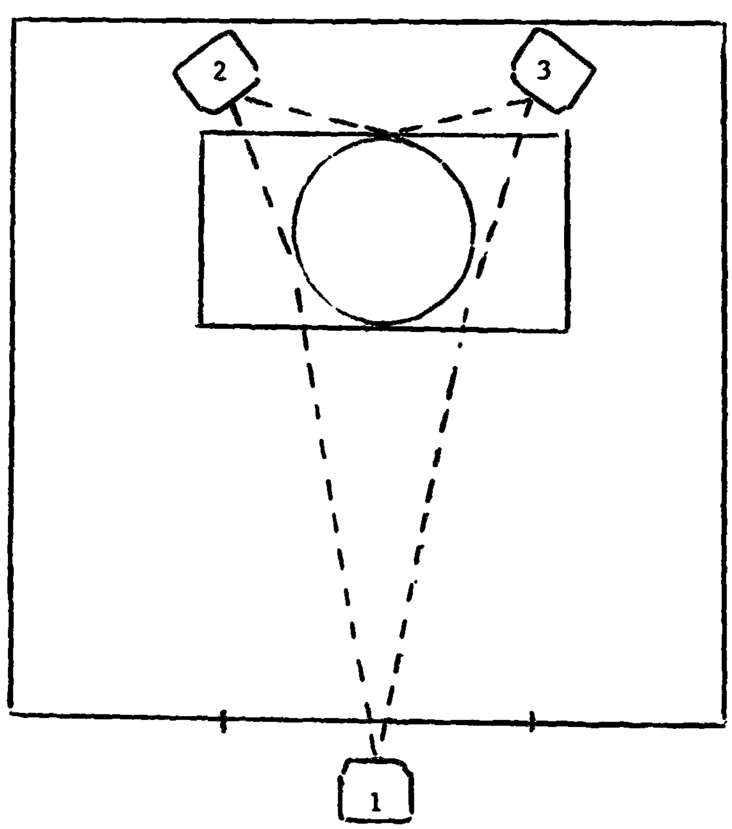


Figure 1

U. Vecario

TESTING CHANGE ORDER

AUG 26 1975

TP No. TP-JPL-1001　　TCO 516　　Date 8/26/75

Unit No. JPL-001　　Originated by John Millar

DESCRIPTION: TEST PLAN, JPL 50 IN. DIA. CHAMBER

Test objectives and instrumentation will be changed as follows:

Section 6 - Instrumentation and Assembly

Step 6.9 should read, Prepare the chamber for water filling.

6.9.1 Delete

6.9.2 Delete

6.9.3 should read, Connect the water fill line.

6.9.4 should read, Fill the chamber with water to the O-ring groove in the aft adapter.

6.9.5 should read, Measure the water level on the aft adapter.

6.9.6 should read, Remove the aft lifting bracket and tie rod.

6.10 should read, Install the aft closure and piston in accordance with Dwg. 60390J62001. Place a liberal ring of seam sealing compound at the junction of the aft closure and the forward face of the aft adapter. A Product Engineering representative will specify and approve the installation of the seam sealing compound.

6.14 A Delete

6.14 C Delete

Section 7 - Test Operations

Step 7.1 Delete

7.2 Delete

7.3 Delete

7.3.1 Delete

7.4 Delete

7.5 Delete

7.12 Delete

7.13 Delete

7.14 Delete

7.15 Delete

7.16 Delete

7.17 Delete

7.18 Delete

Test Engineering

Product Engineering

Test Operations

W. F. Matthews 8/26/75

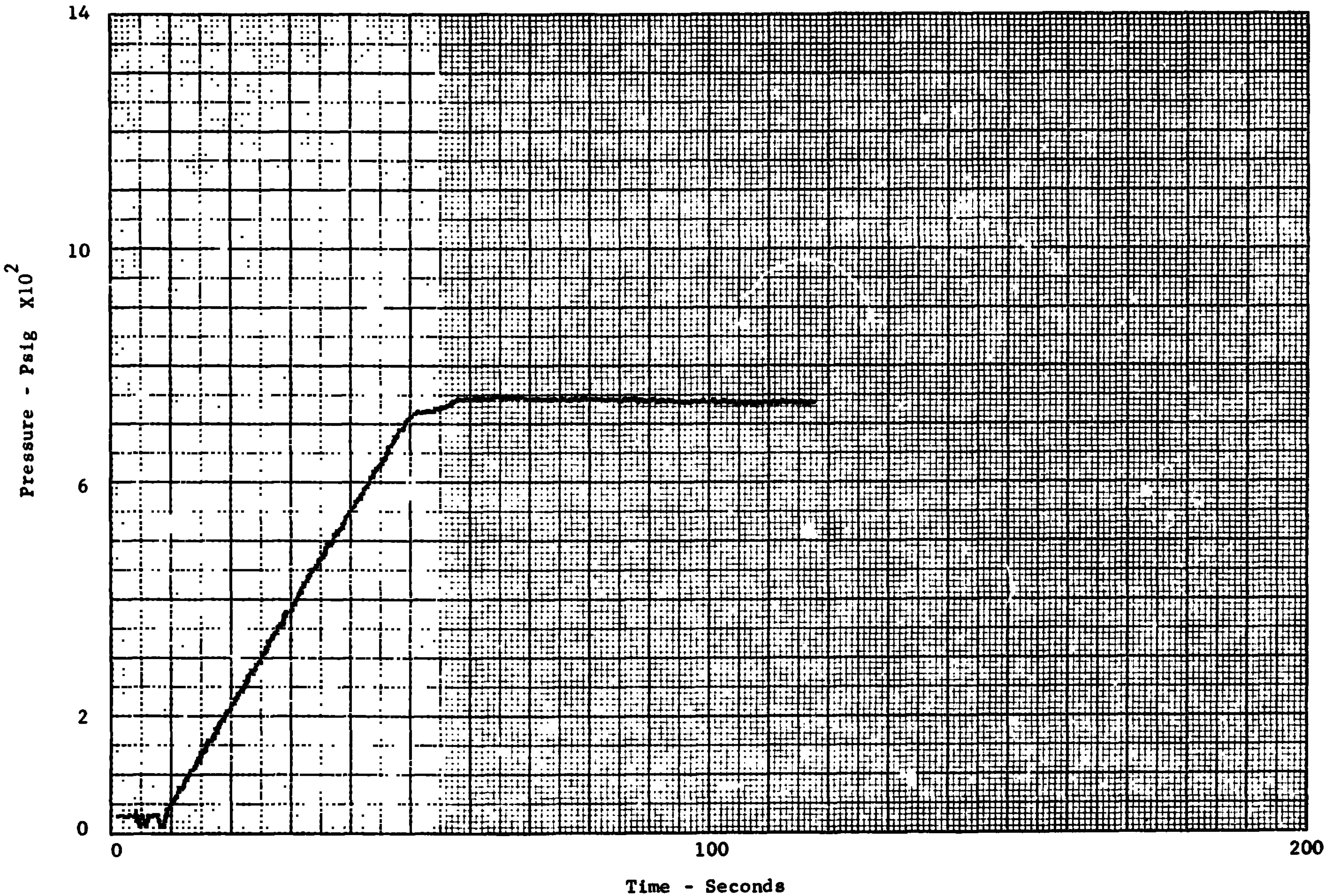
Safety

APPENDIX B

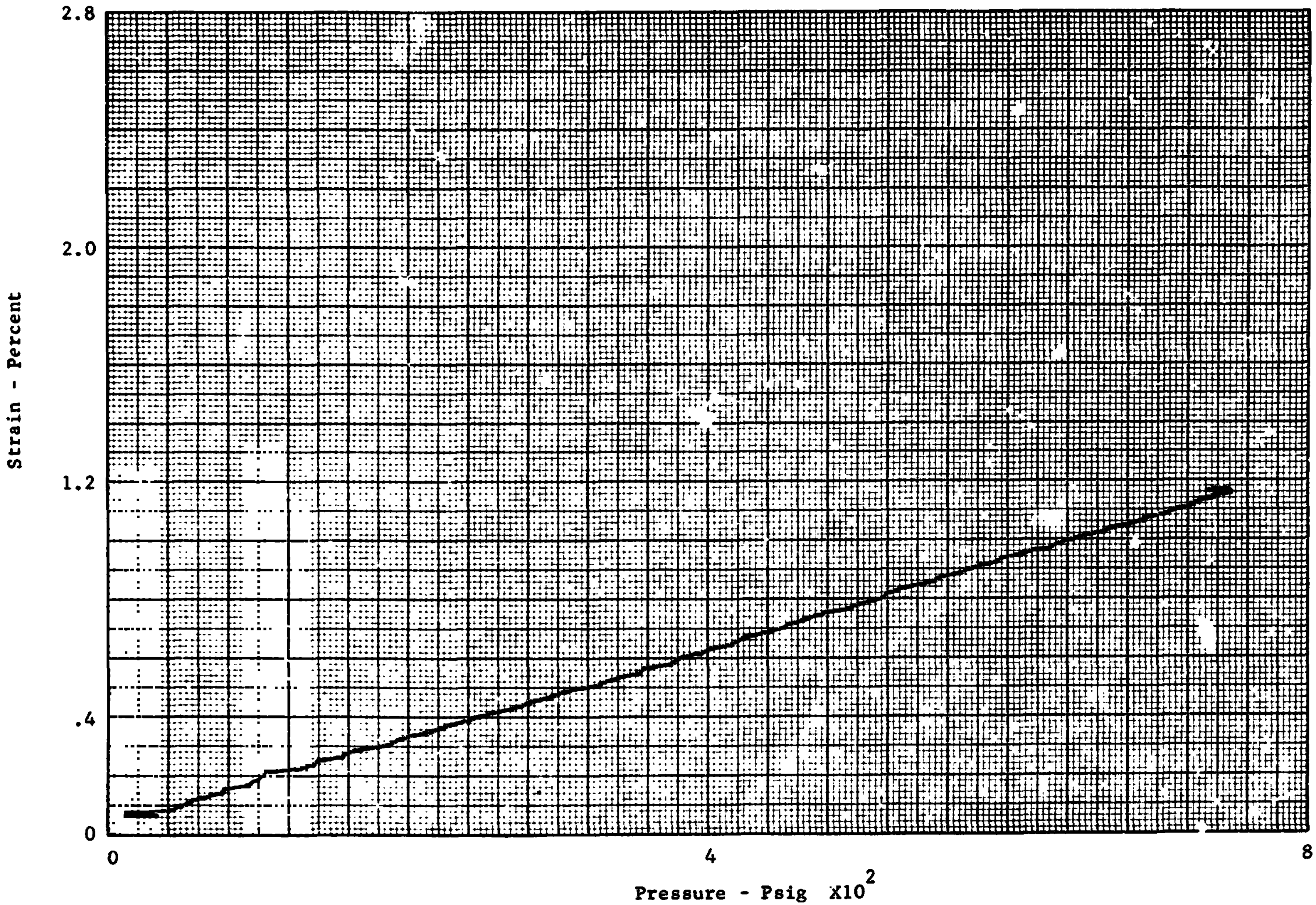
RESULTS OF HYDROPROOF TEST OF

JPL CHAMBER 001

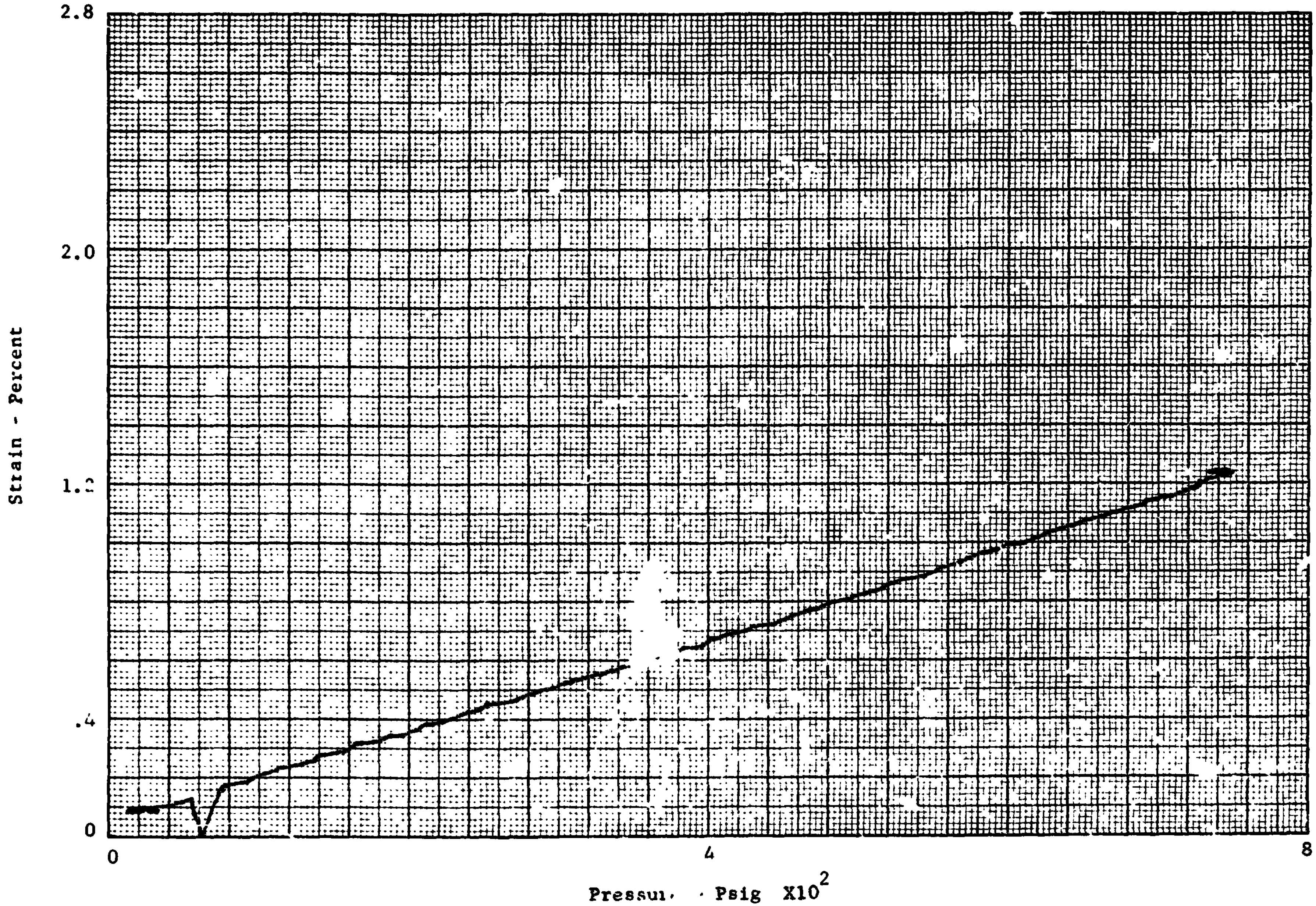
JPL 50 " CHAMBER PROOF TEST JPL001
RANGE ROUND NO ST3230
DATE TESTED 08-27-75
PRESSURE P1P2 AVG
PLOT RATE 30 SPS



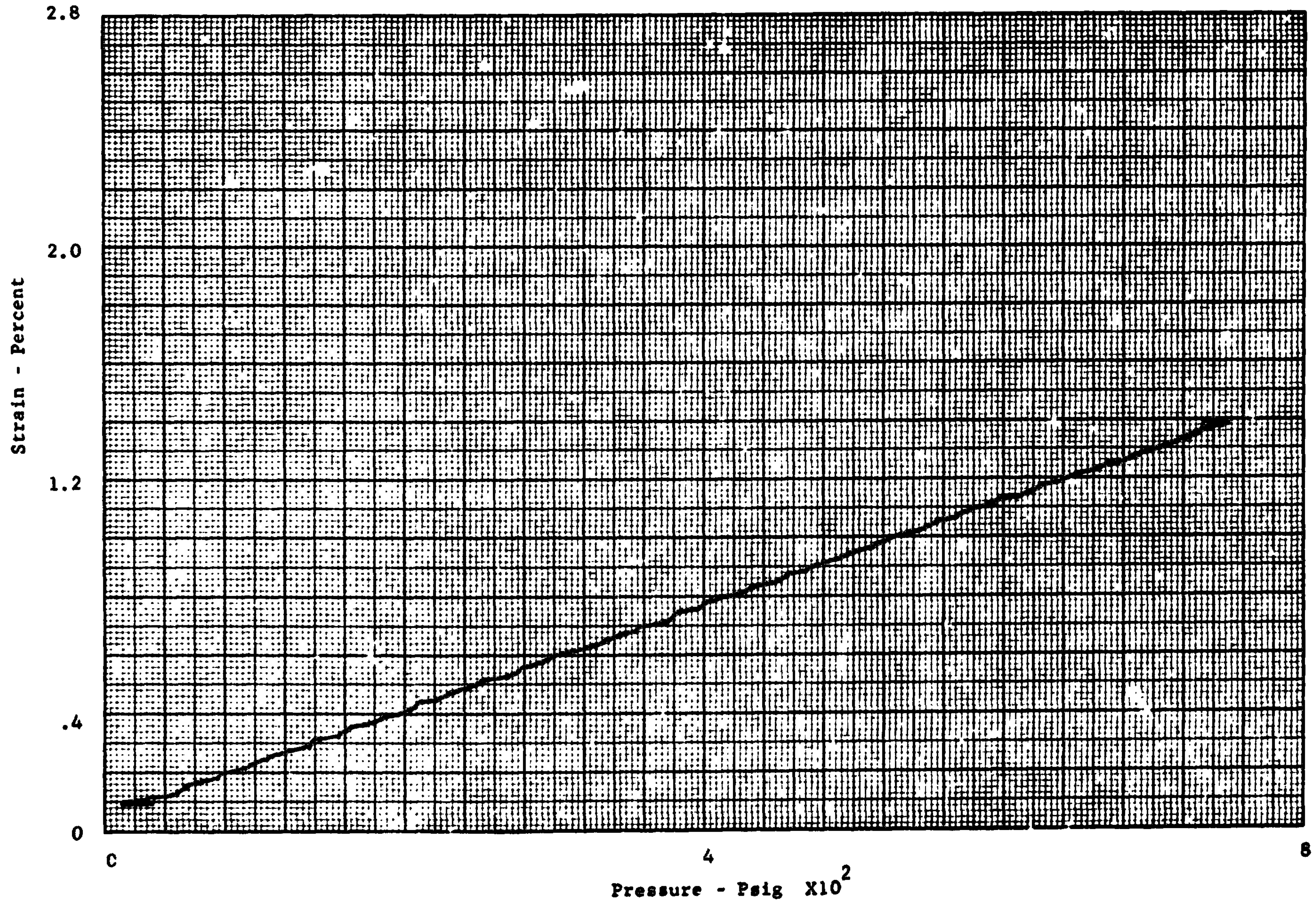
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 1
PLOT RATE 30 SPS



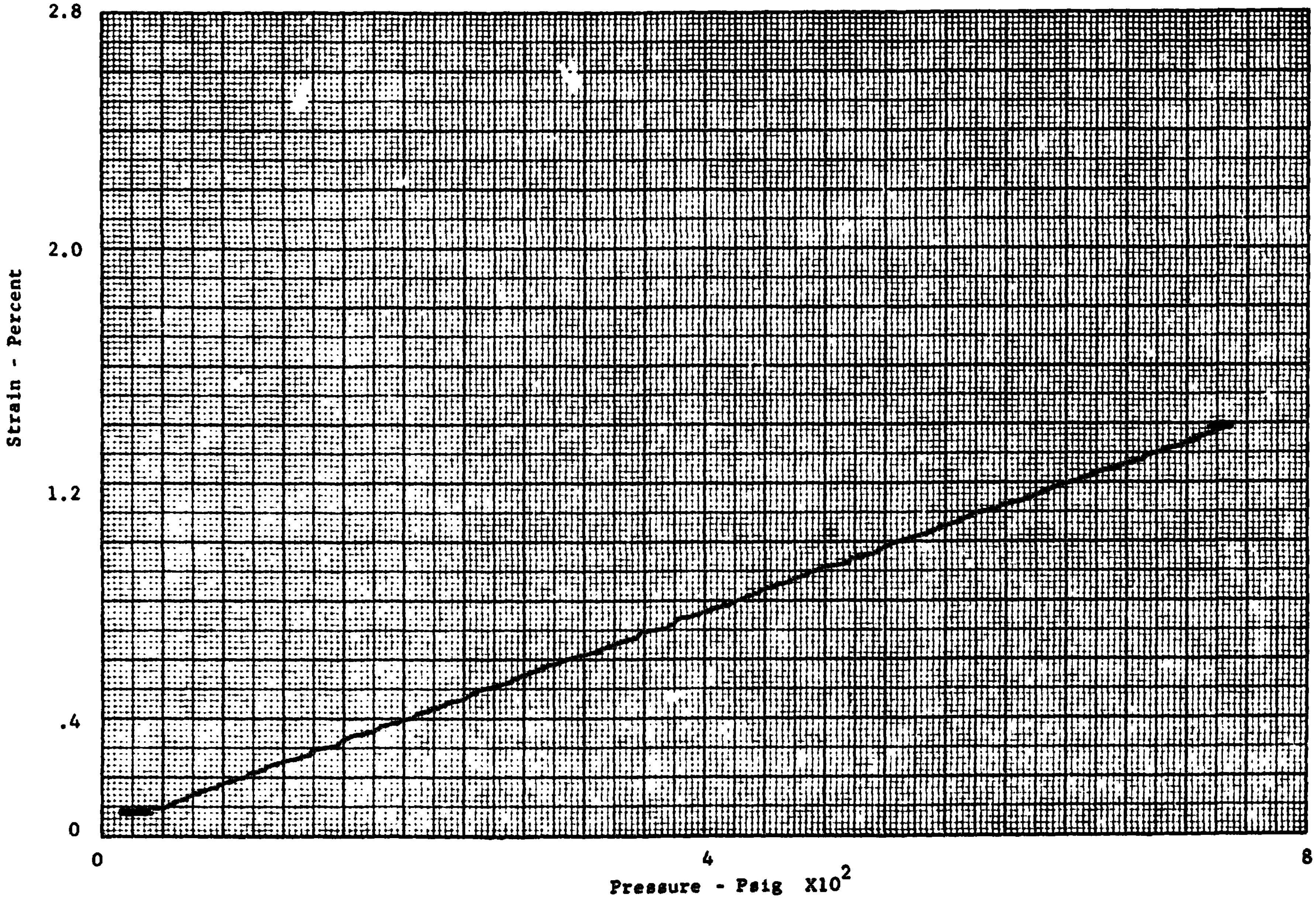
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 2
PLOT RATE 30 SPS



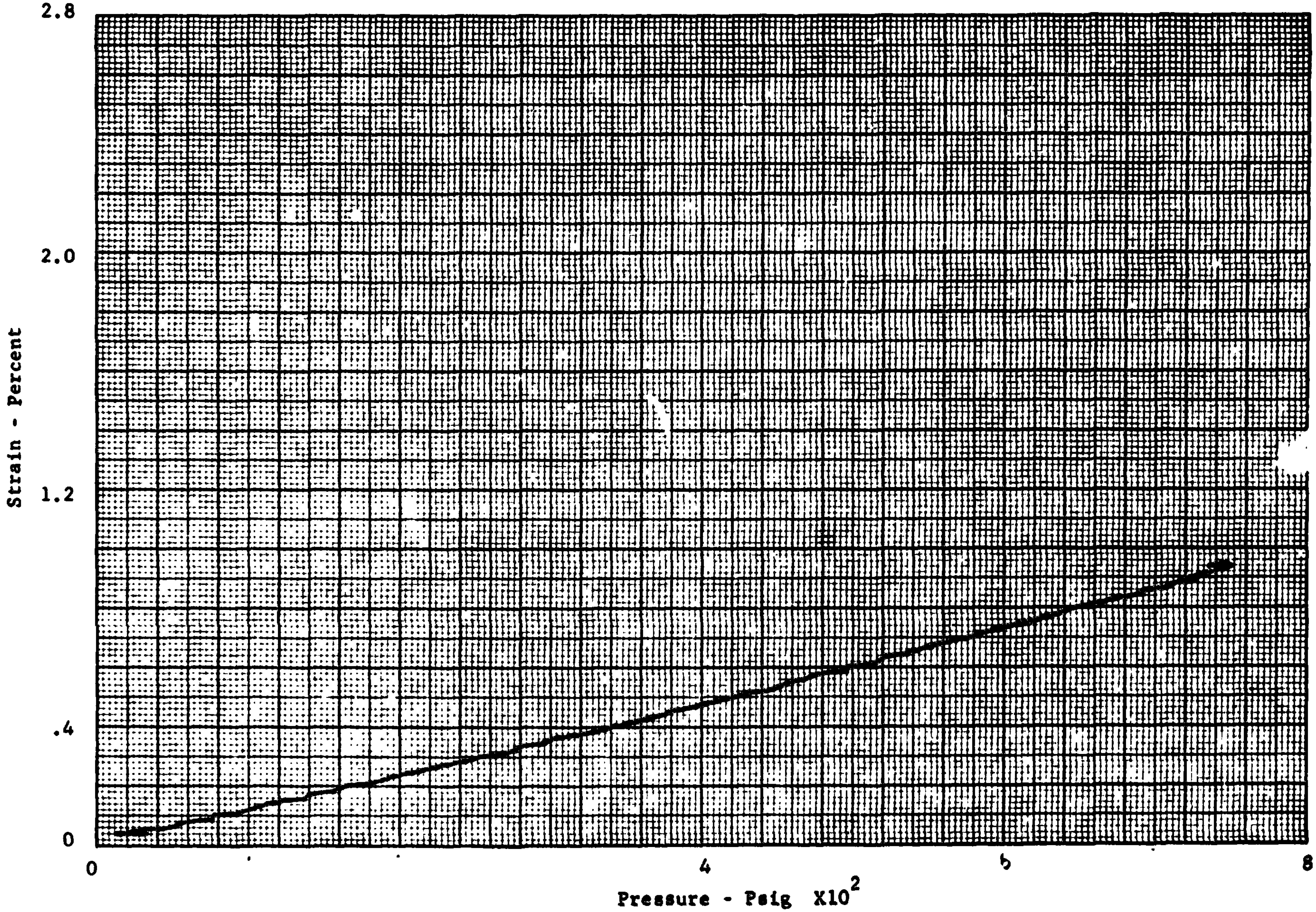
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 3
PLOT RATE 30 SPS



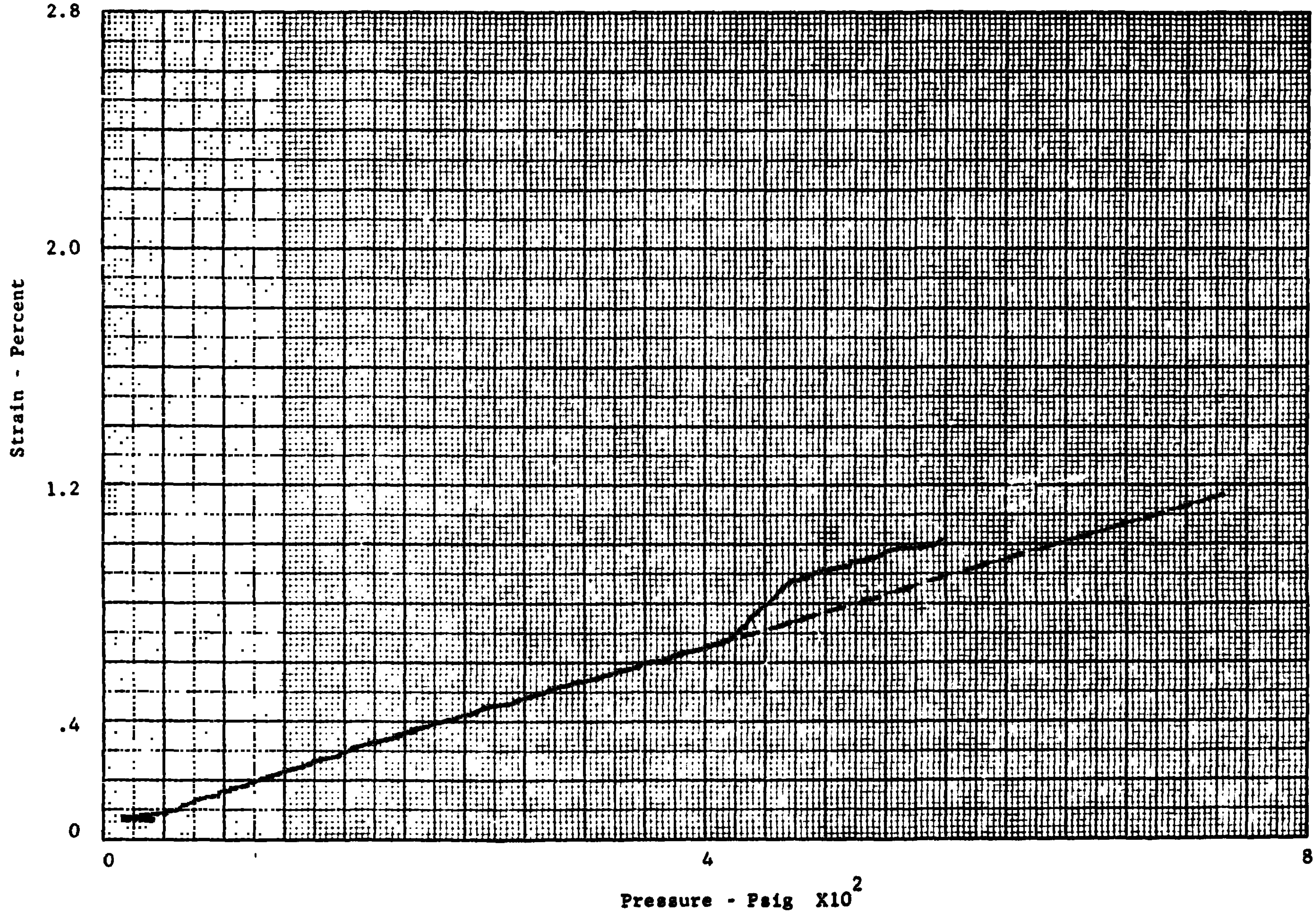
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 4
PLOT RATE 30 SPS

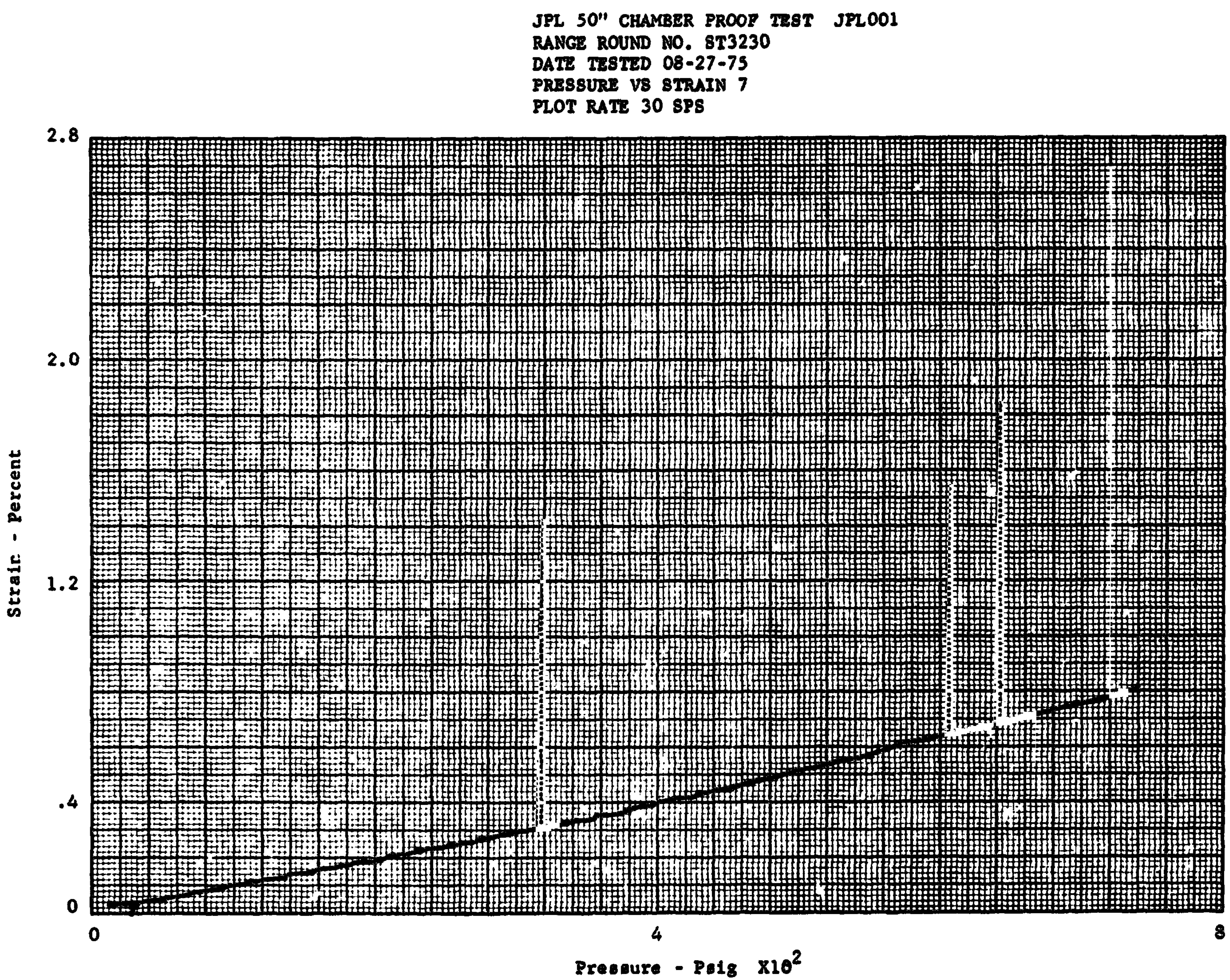


JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 5
PLOT RATE 30 SPS



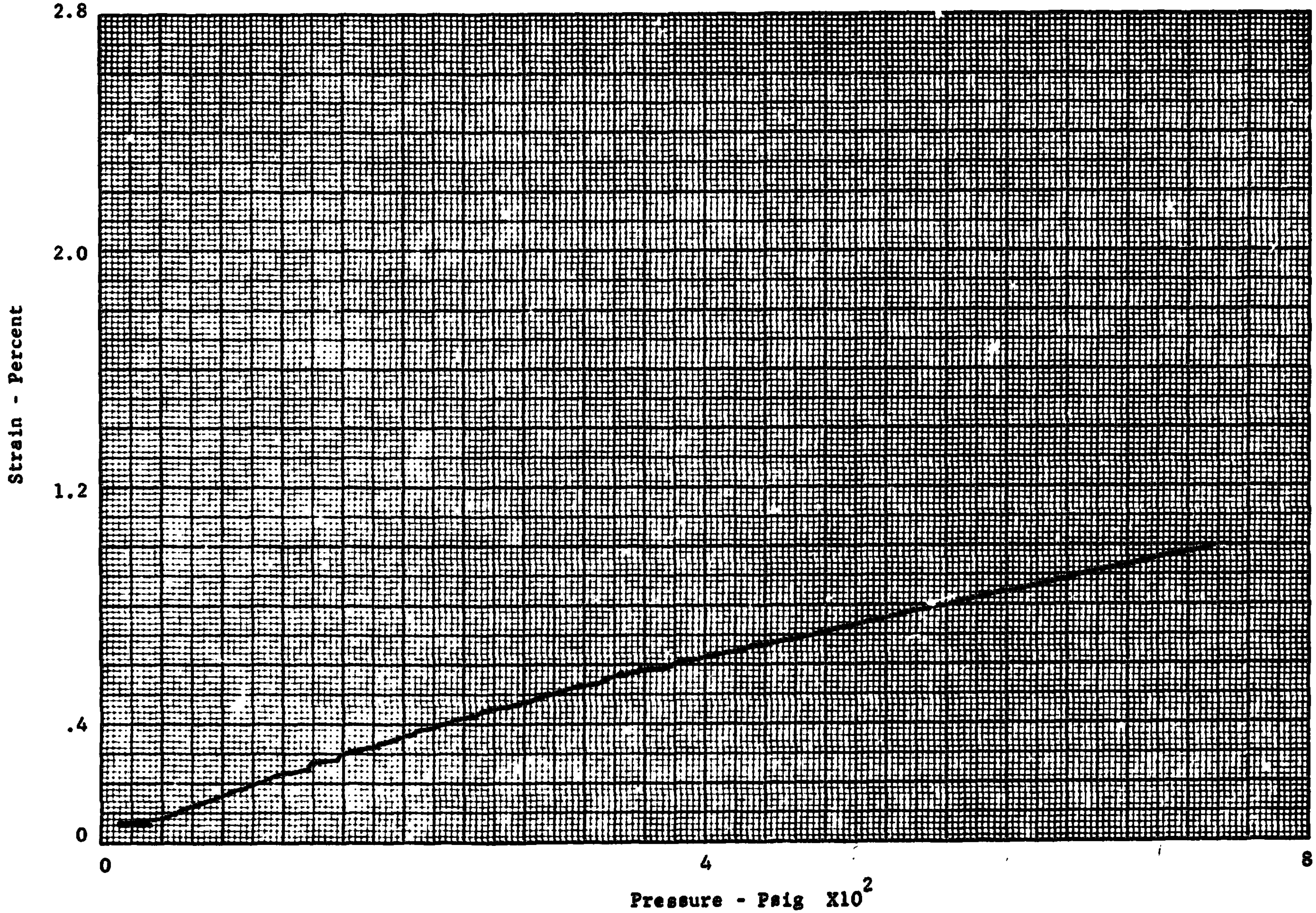
JPL 50" CHAMBER PROOF TEST JPL 001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 6
PLOT RATE 30 SPS



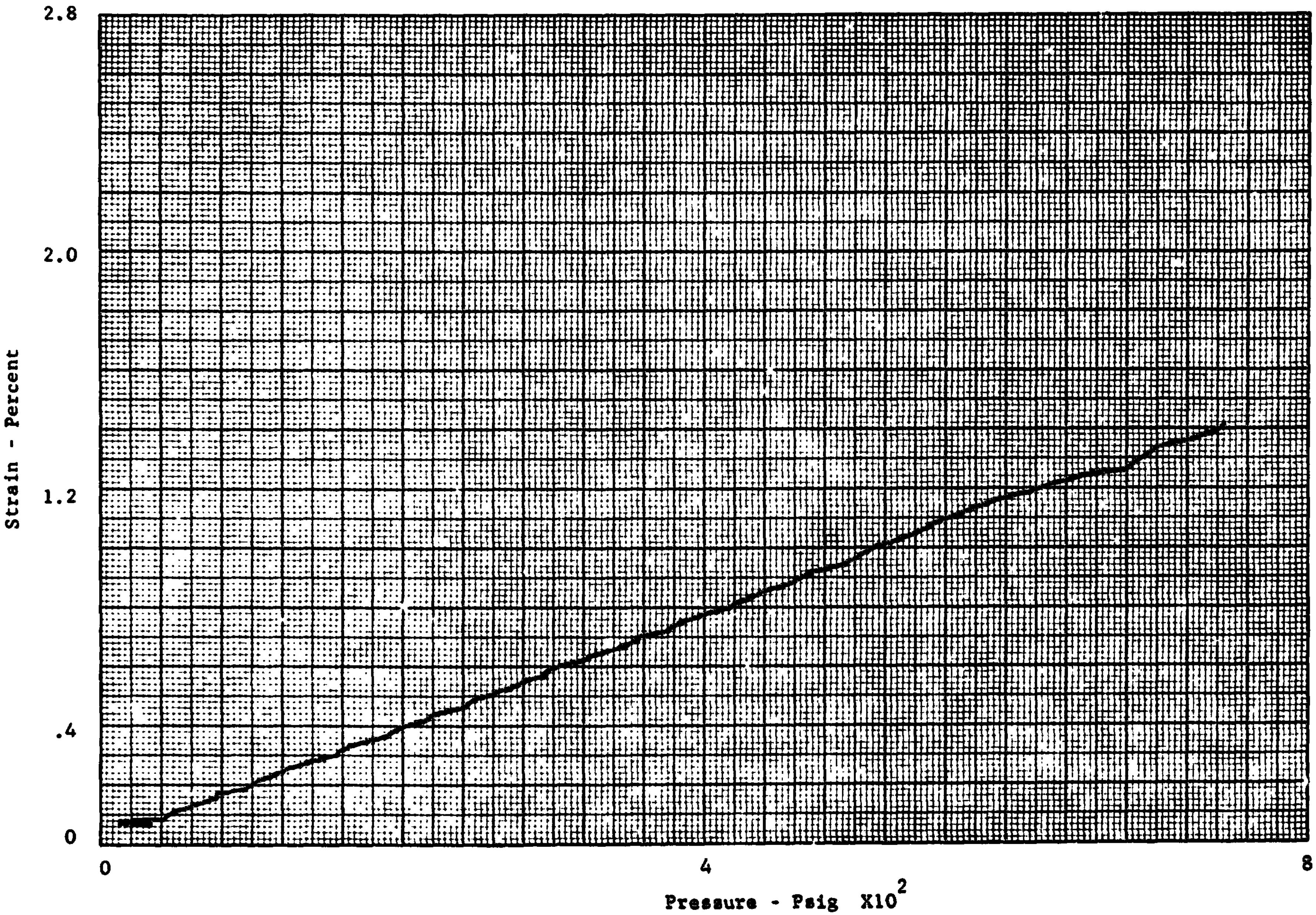


JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 7
PLOT RATE 30 SPS
2.8
2.0
1.2
.4
0
Strain - Percent
0
4
8
Pressure - Psig X10^2

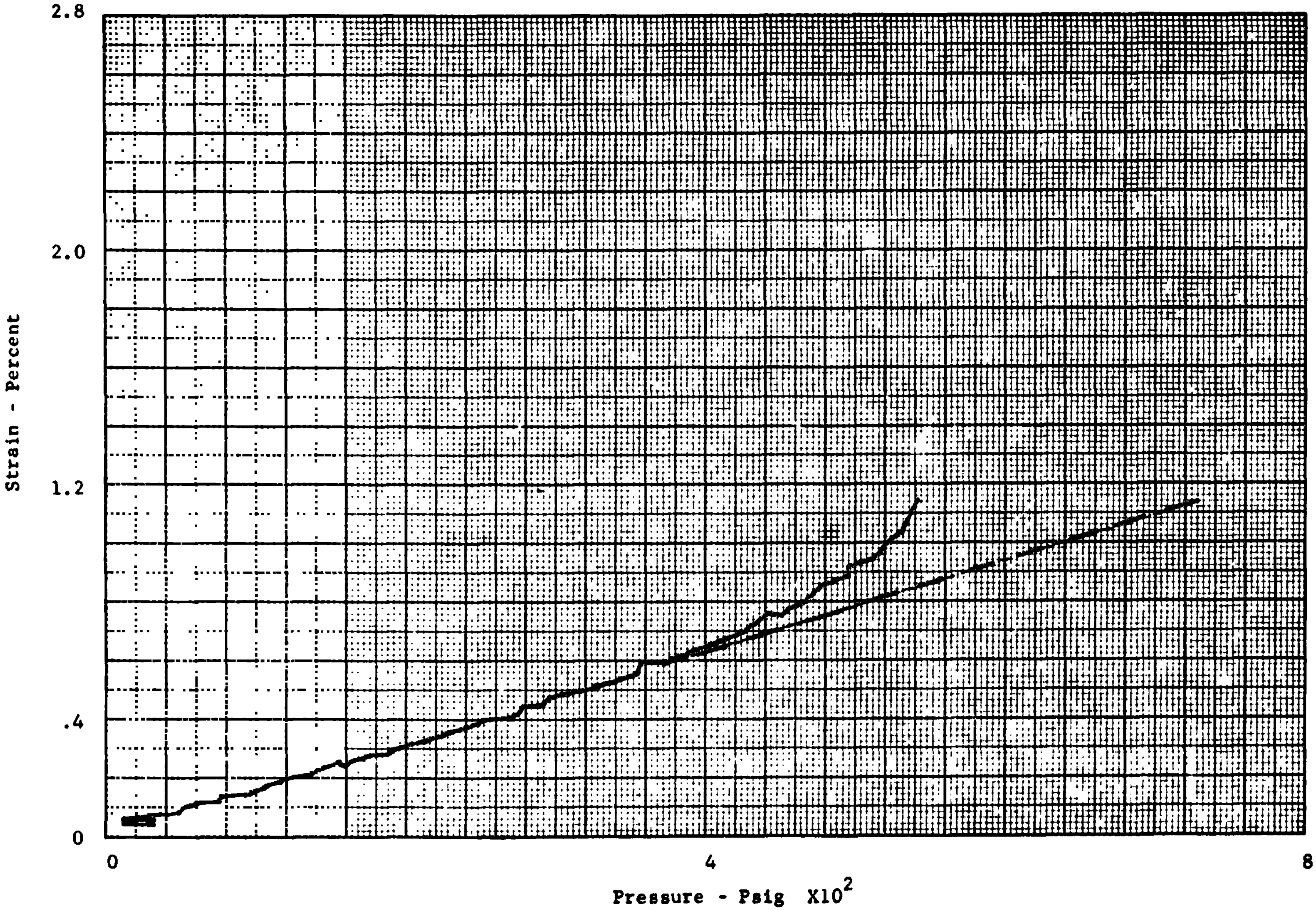
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 8
PLOT RATE 30 SPS



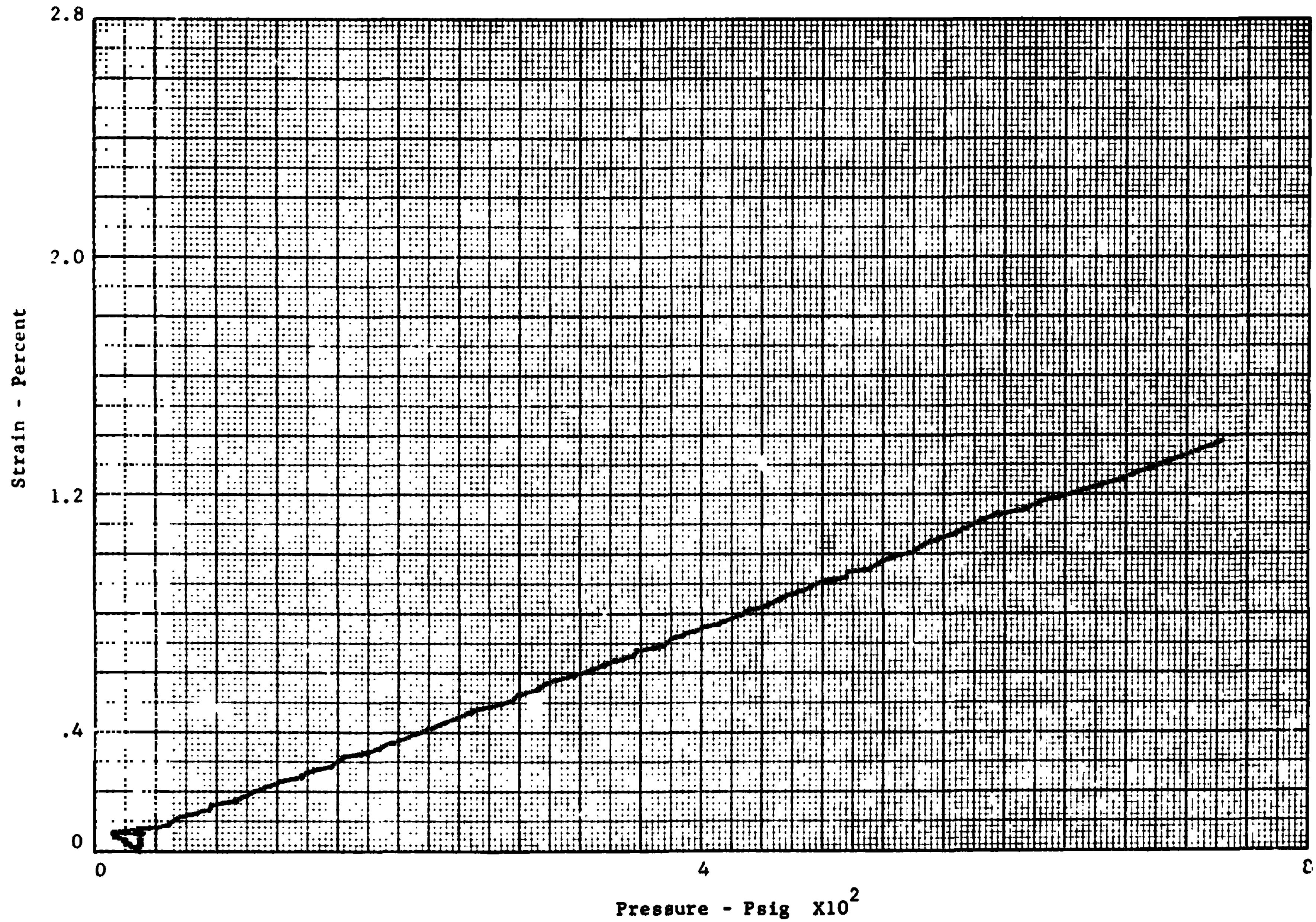
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 9
PLOT RATE 30 SPS



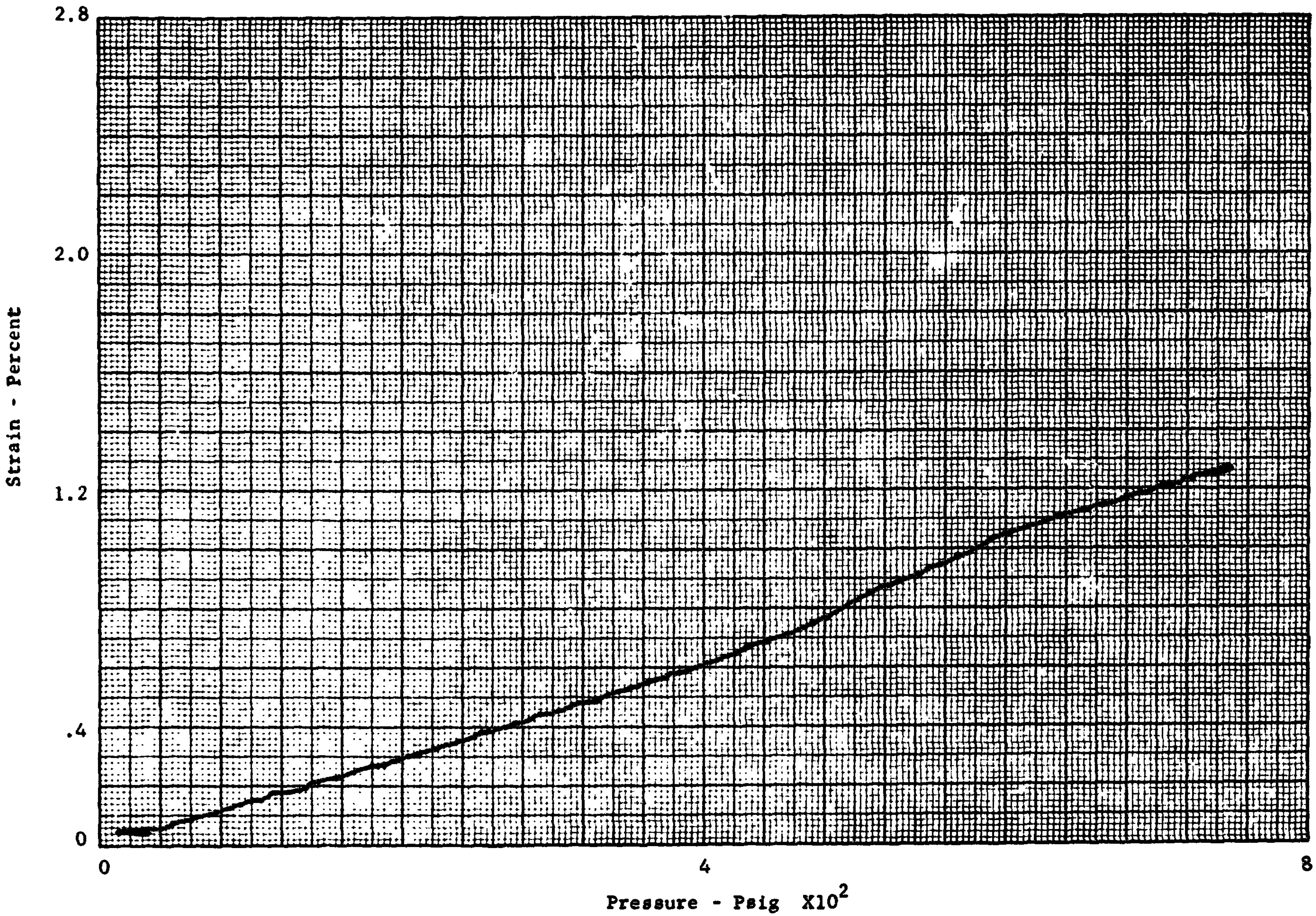
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 10
PLOT RATE 30 SPS



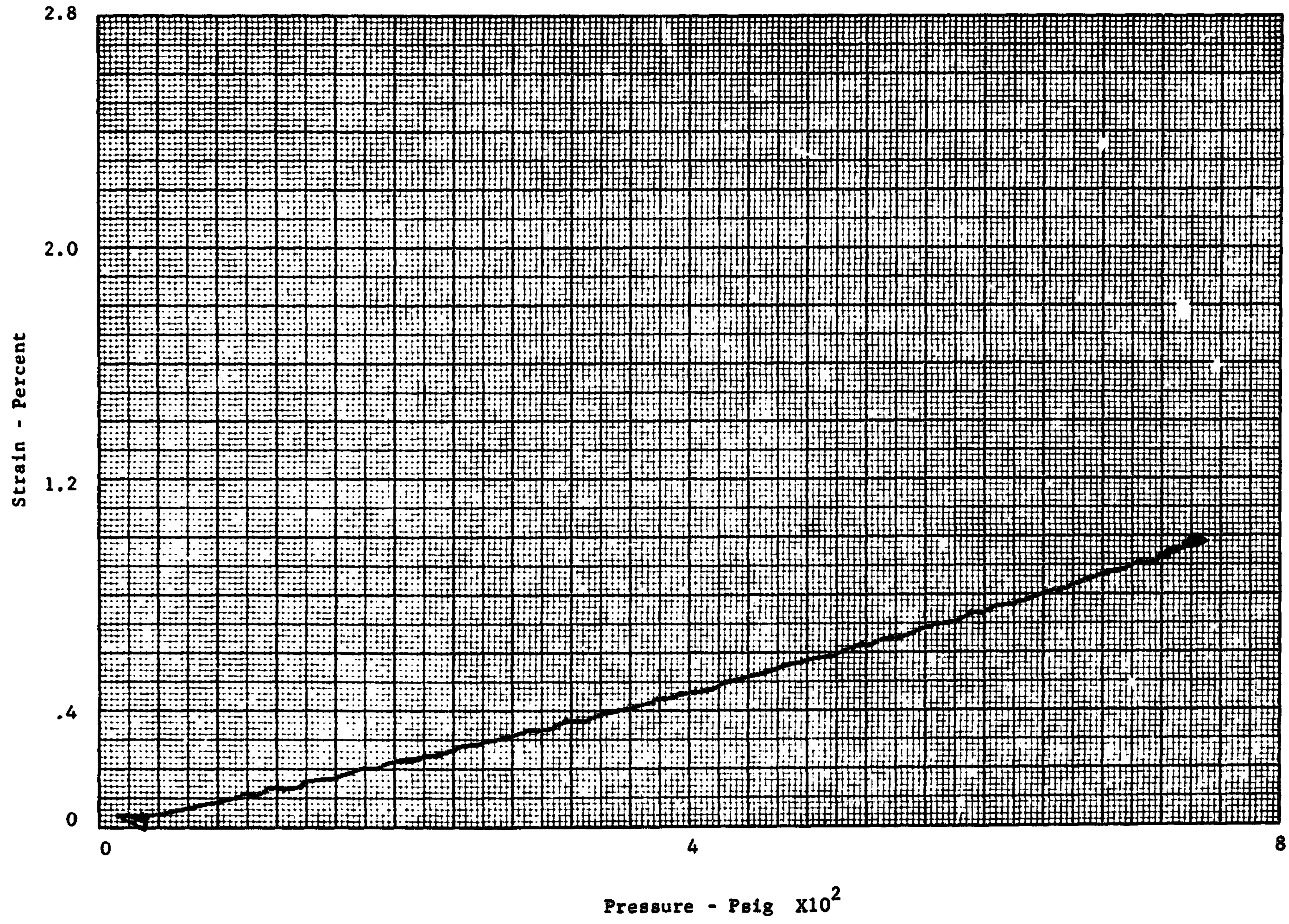
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 11
PLOT RATE 30 SPS

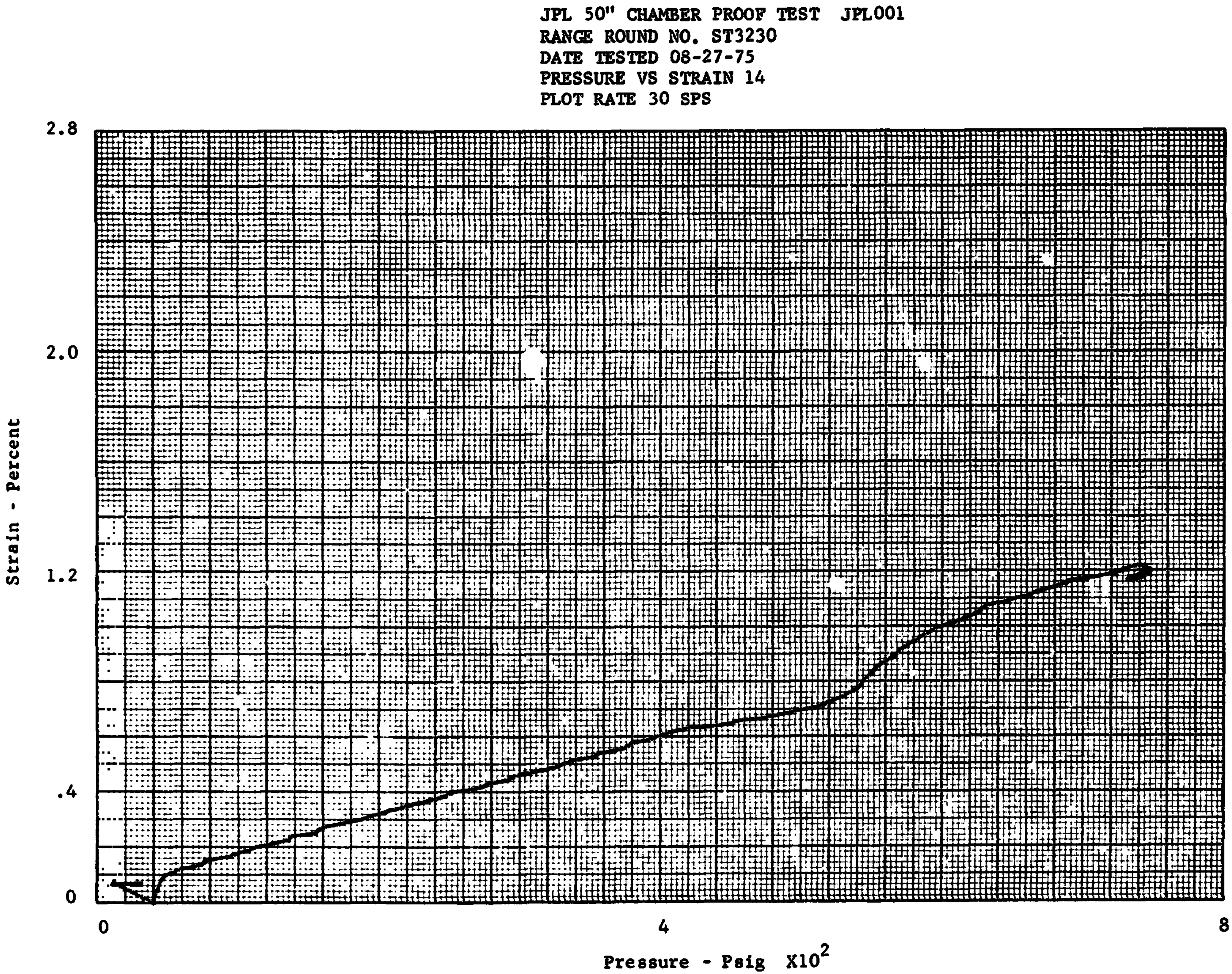


JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 12
PLOT RATE 30 SPS

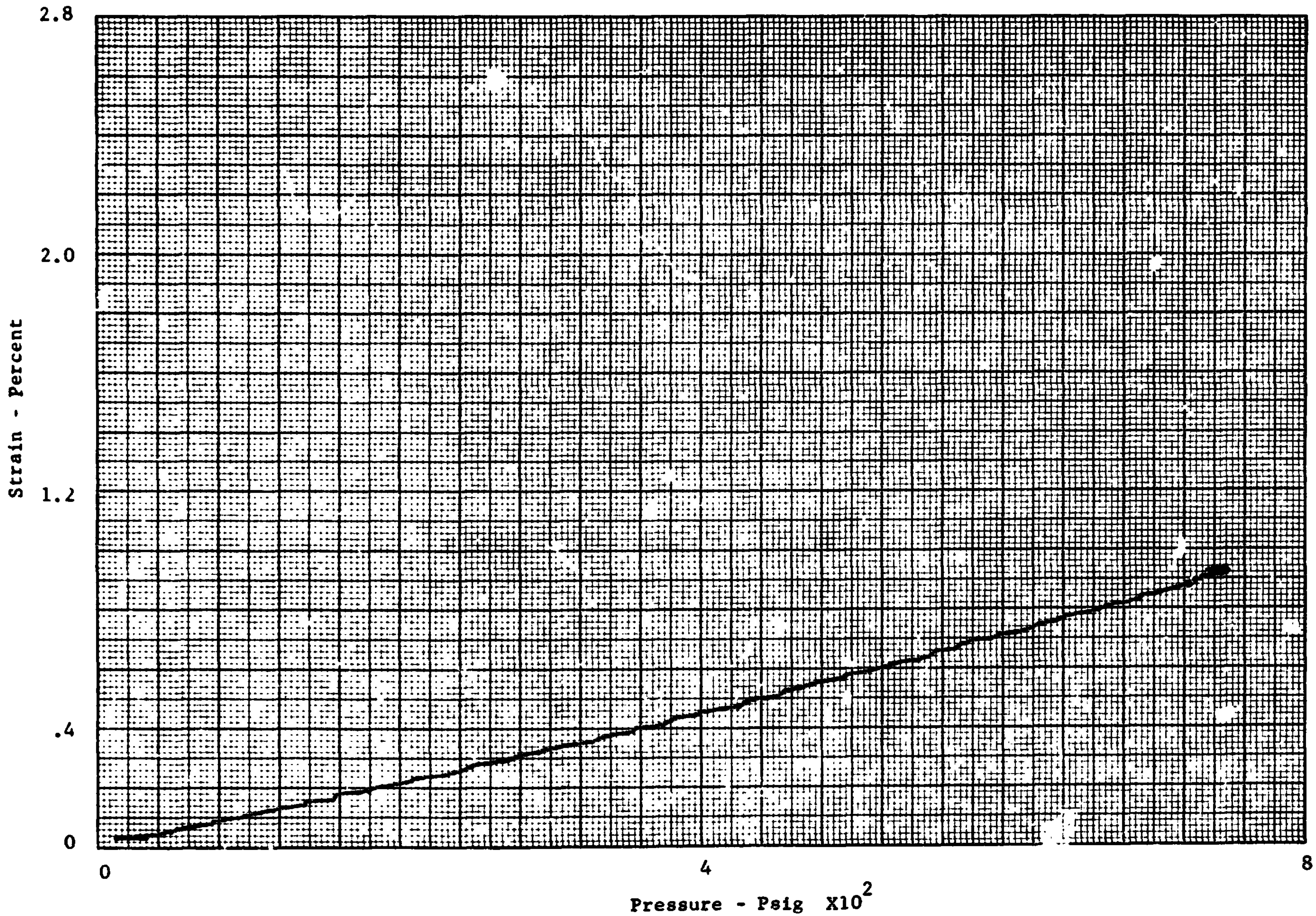


JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 13
PLOT RATE 30 SPS

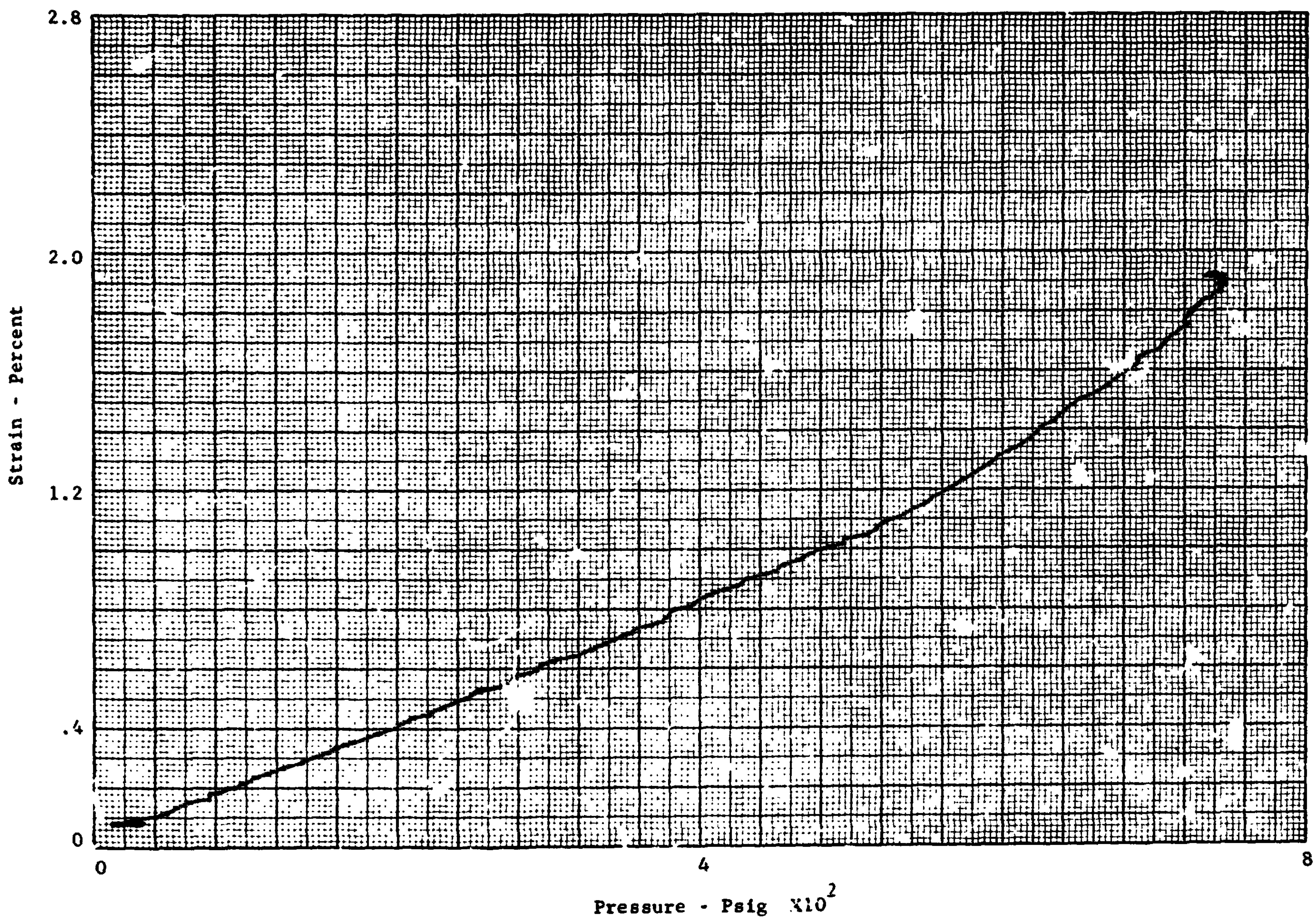



JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 14
PLOT RATE 30 SPS
2.8
2.0
1.2
.4
0
Strain - Percent
0
4
8
Pressure - Psig X10²

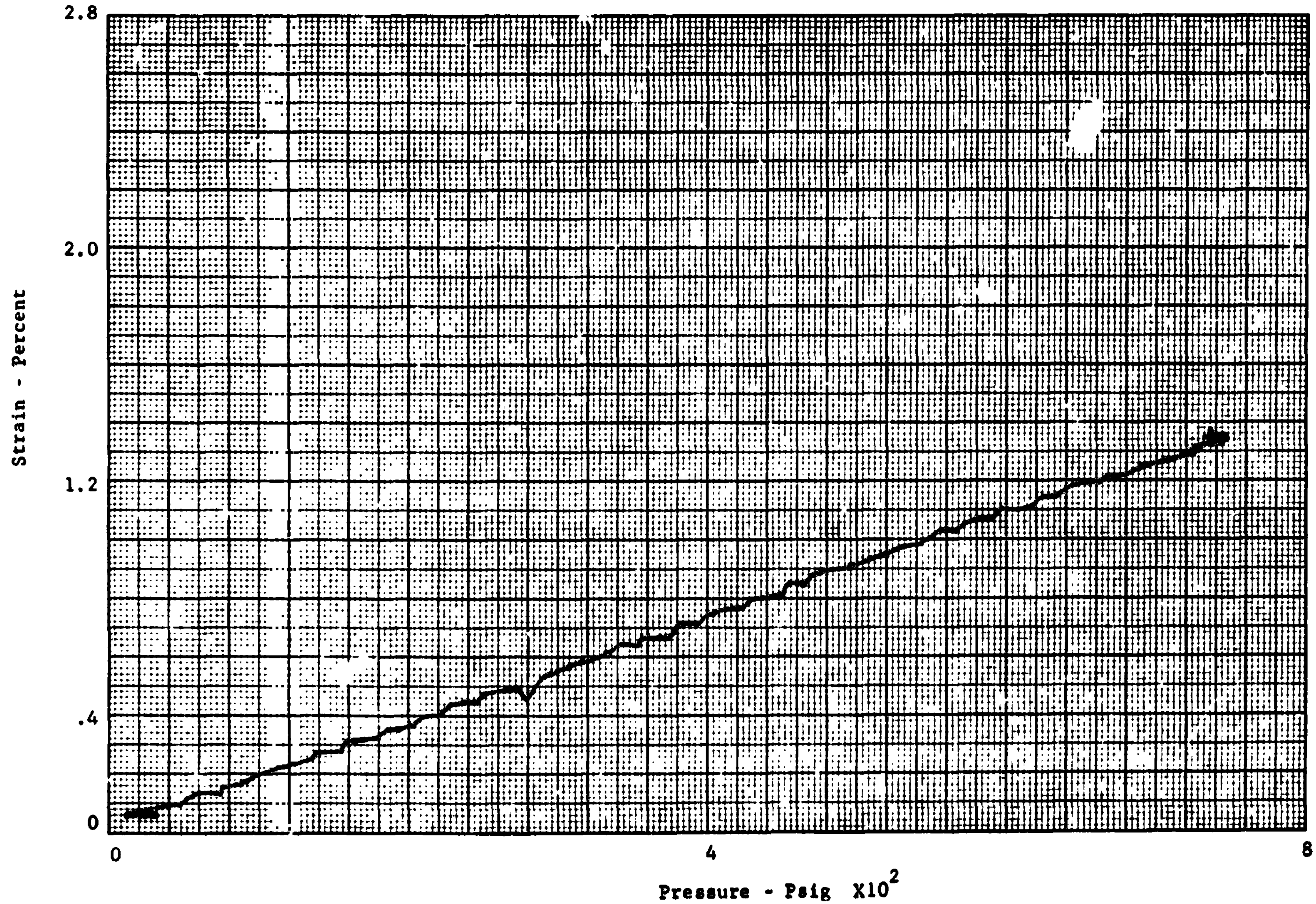
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 15
PLOT RATE 30 SPS



JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 16
PLOT RATE 30 SPS



JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 17
PLOT RATE 30 SPS



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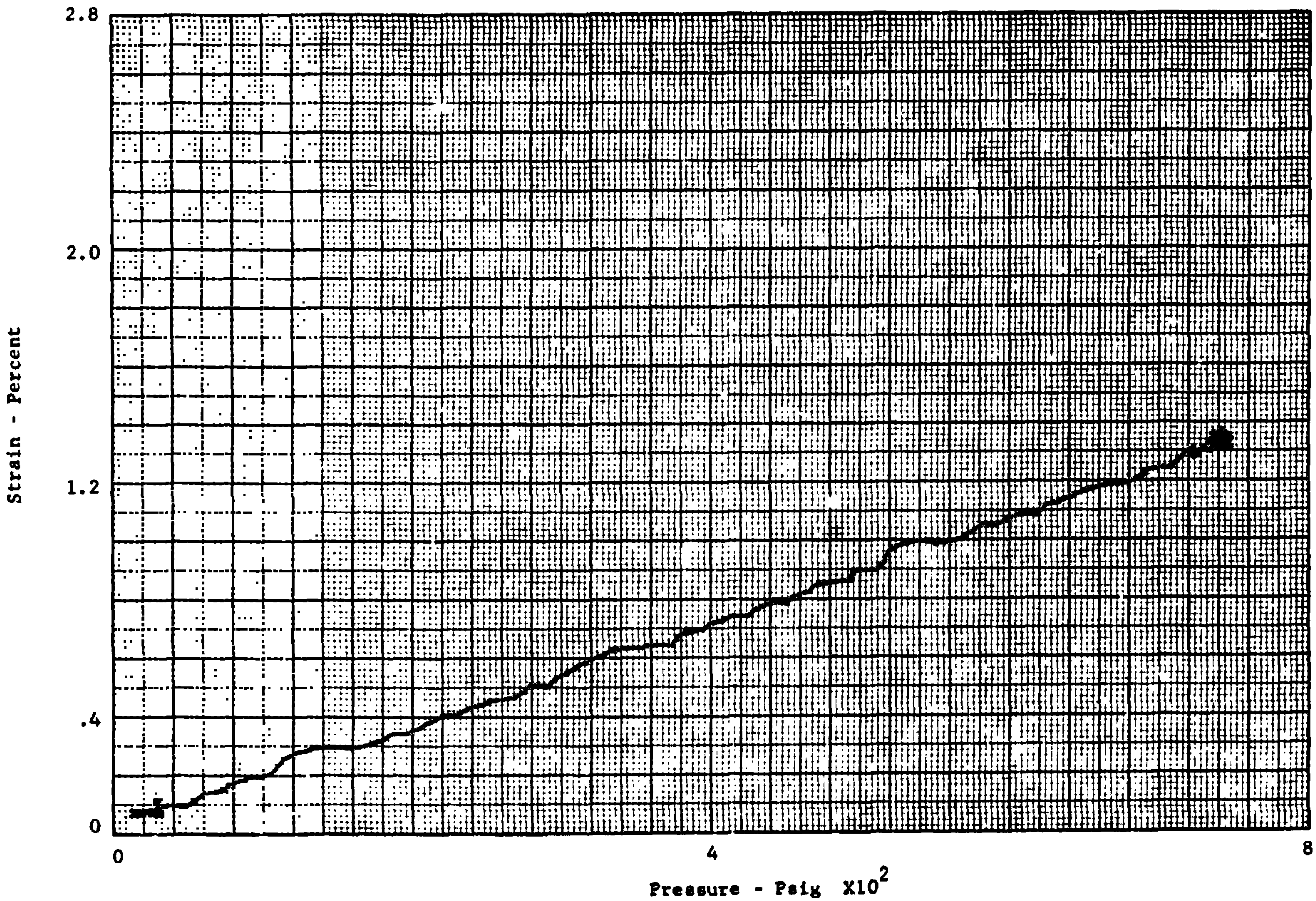
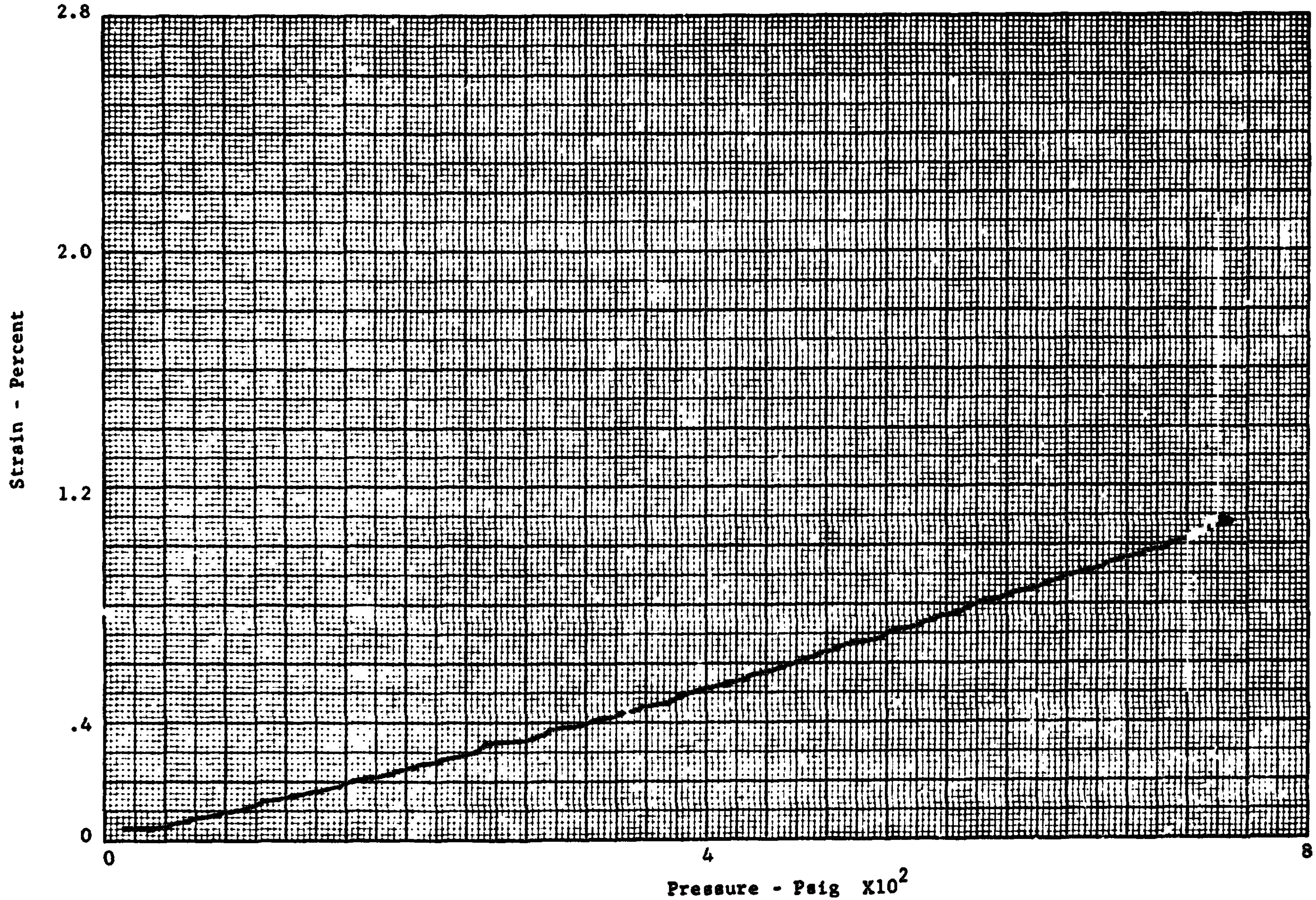
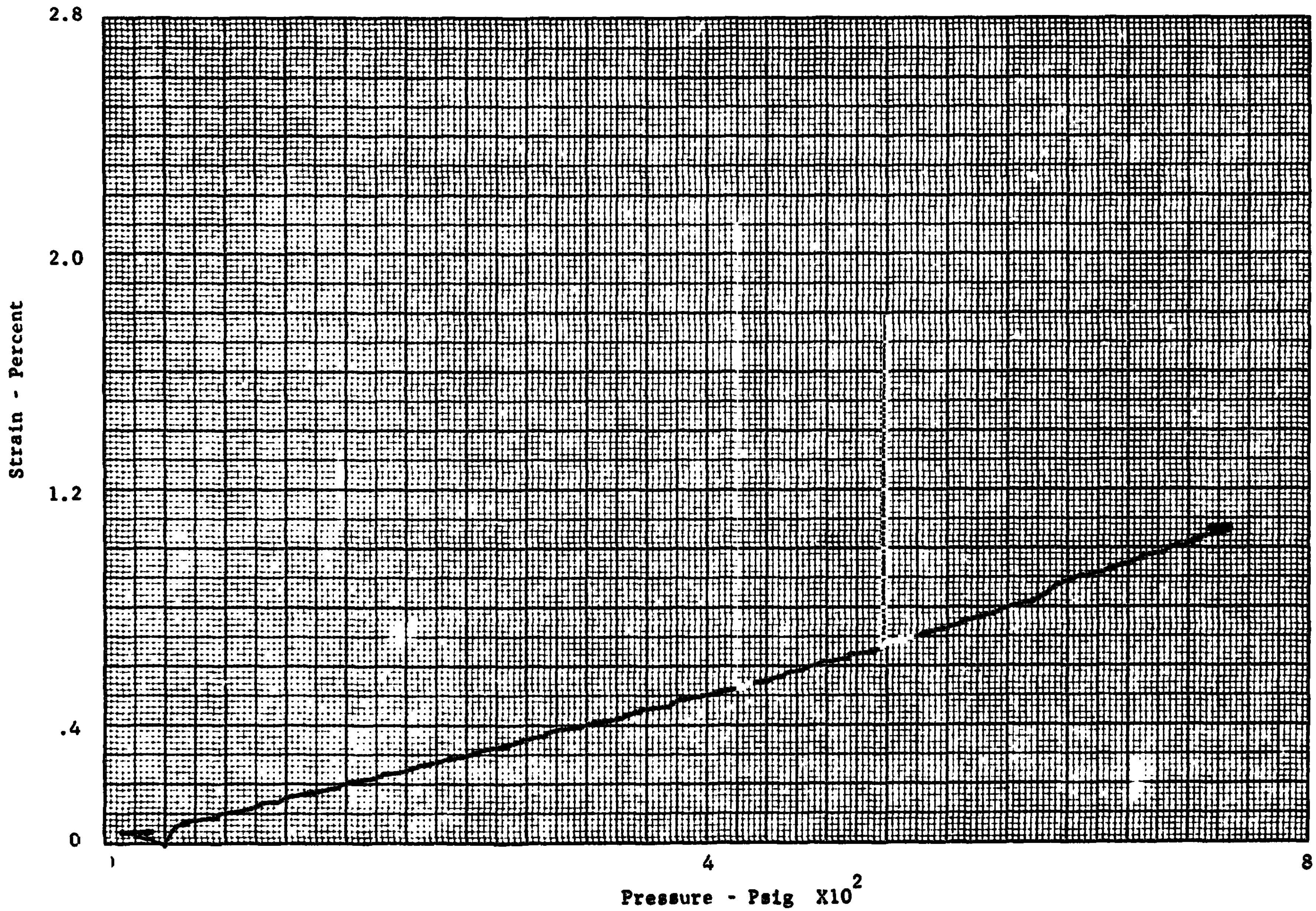
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 18
PLOT RATE 30 SPS



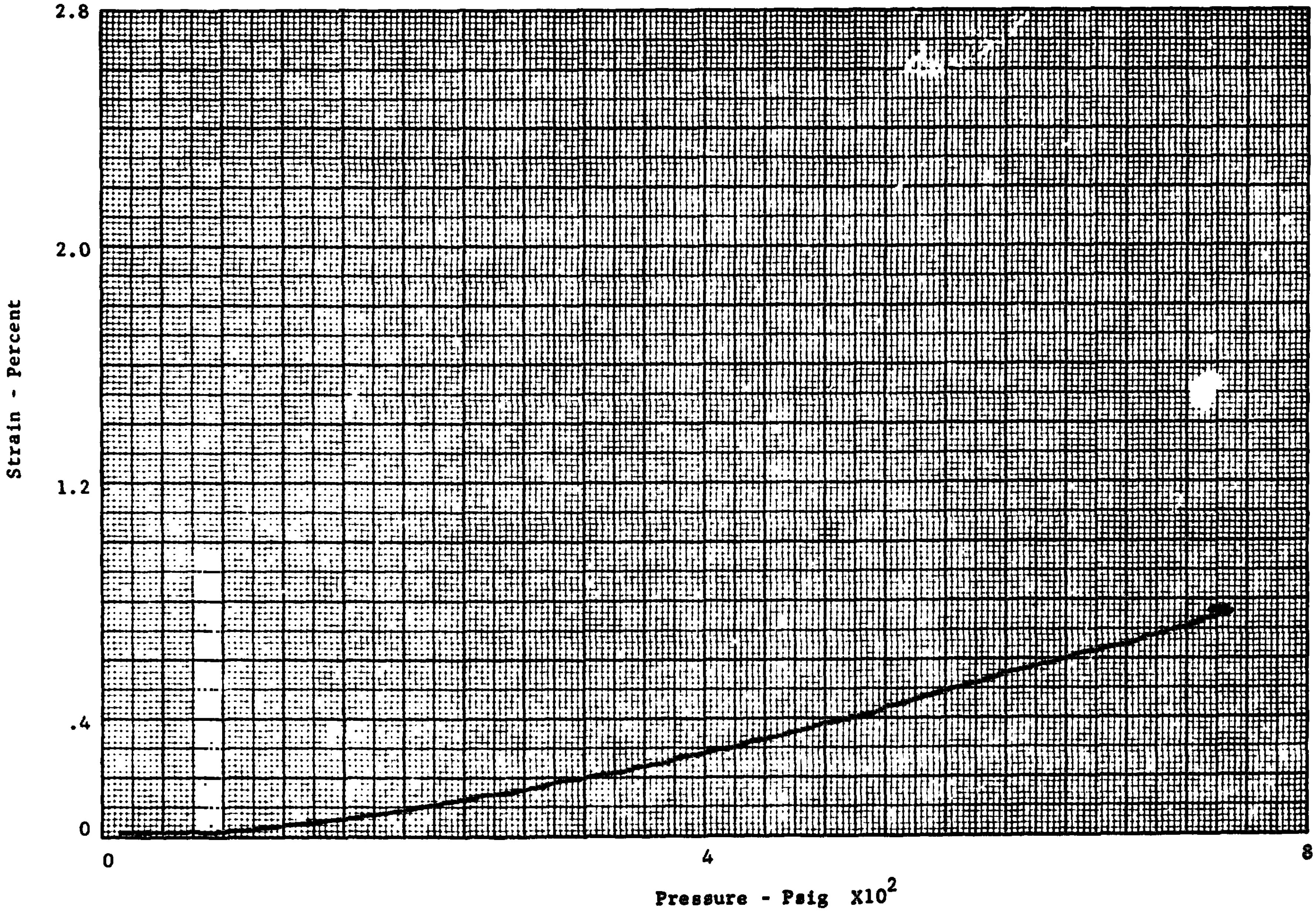
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 19
PLOT RATE 30 SPS



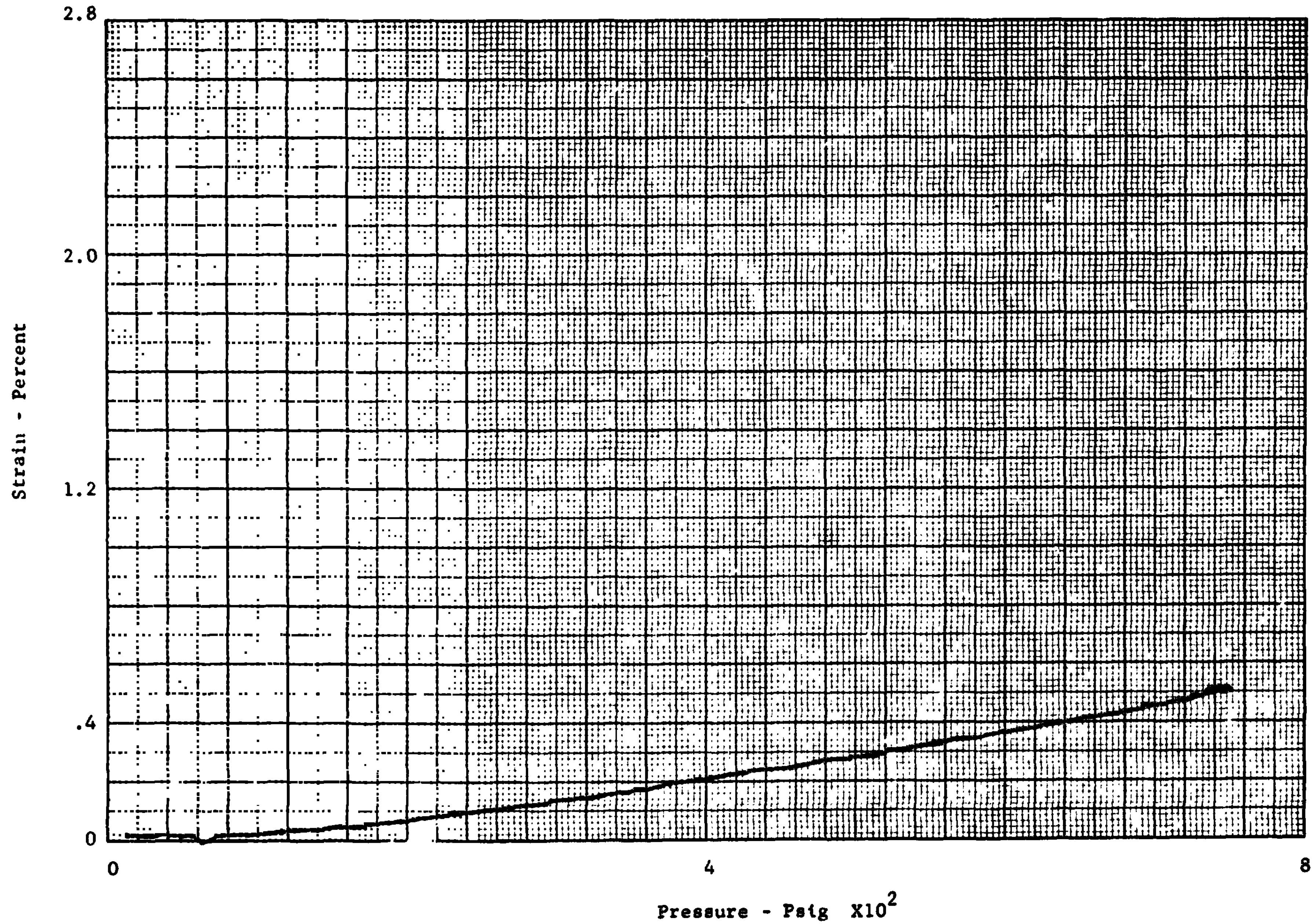
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 20
PLOT RATE 30 SPS



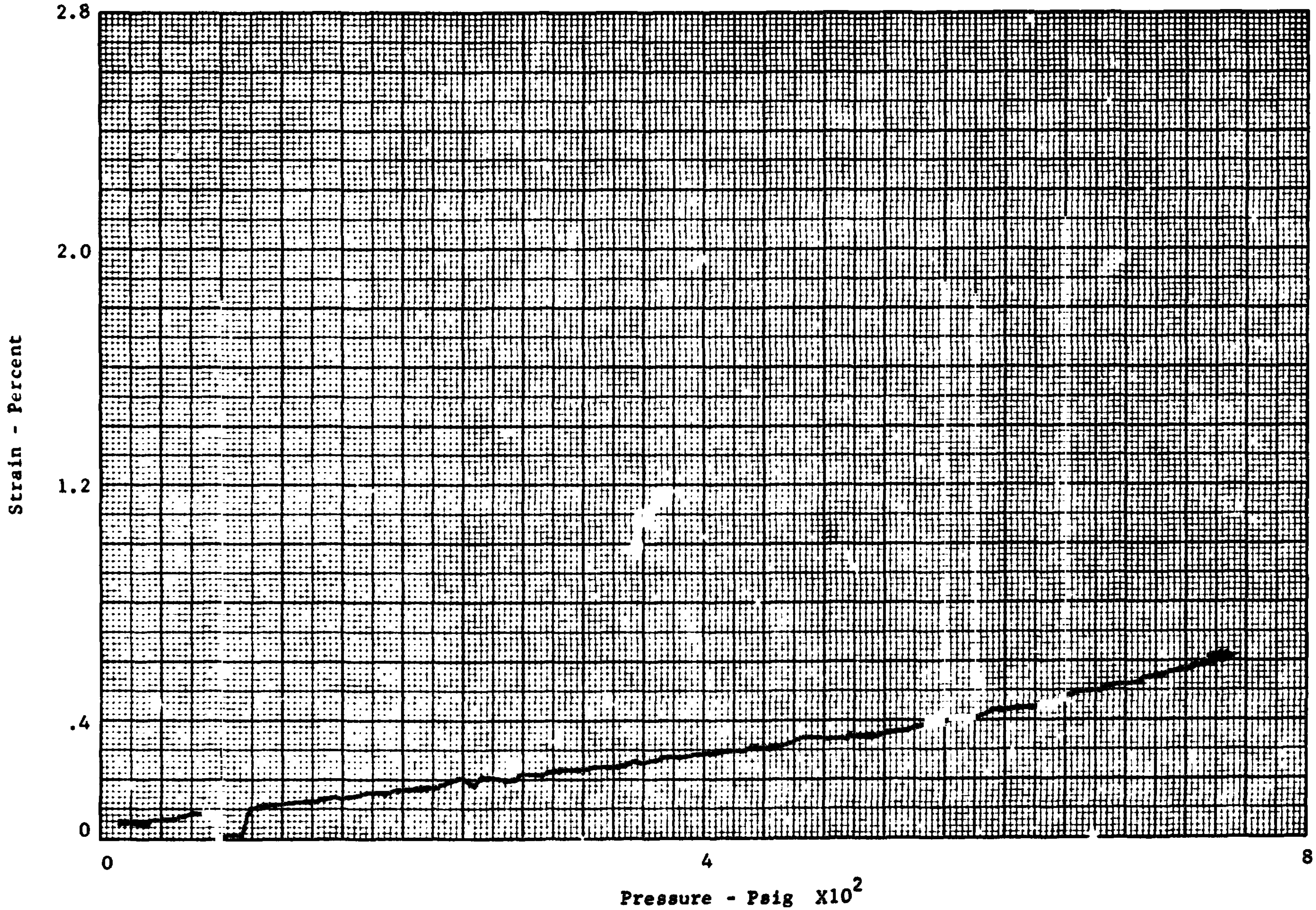
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 21
PLOT RATE 30 SPS



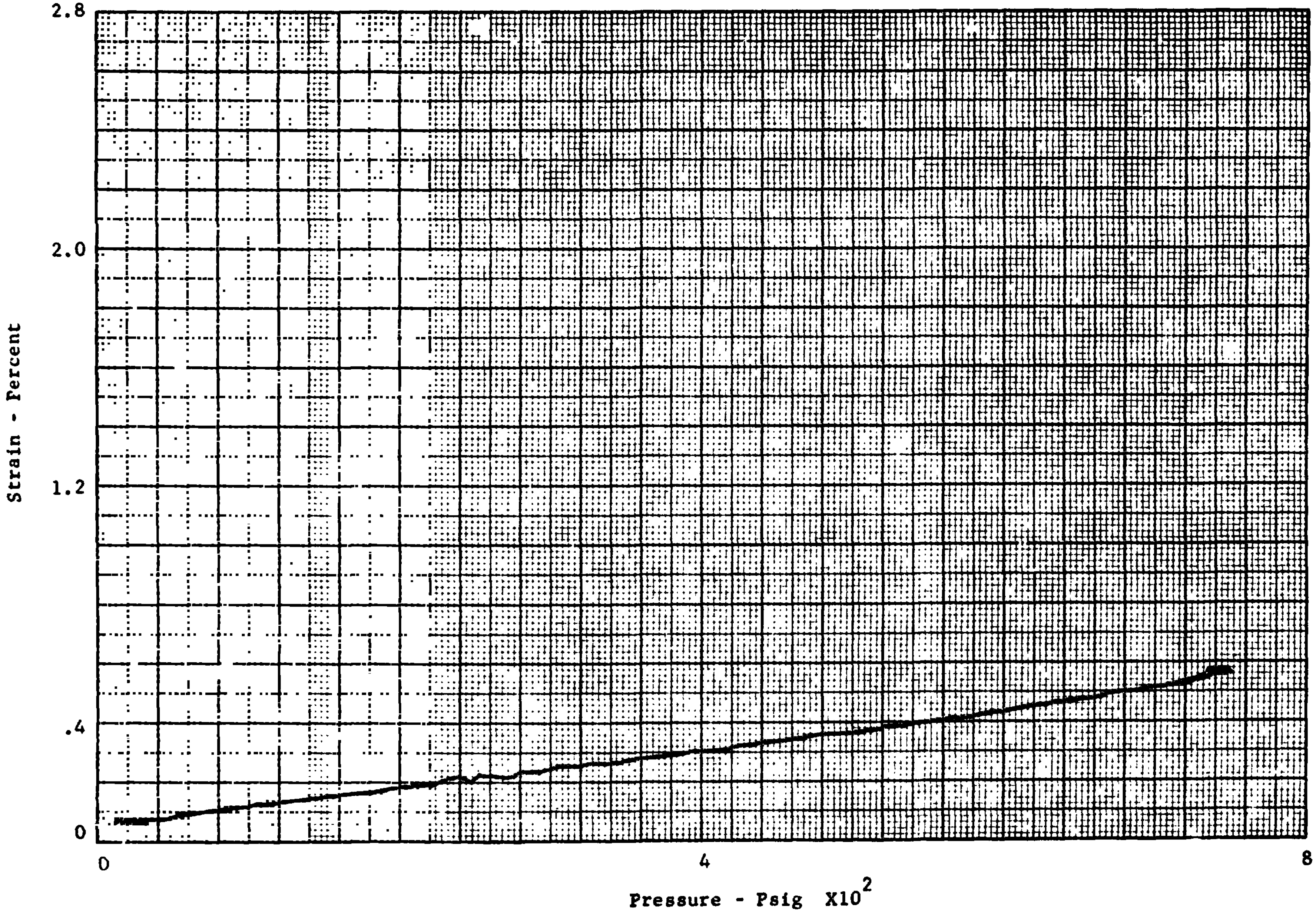
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 22
PLOT RATE 30 SPS



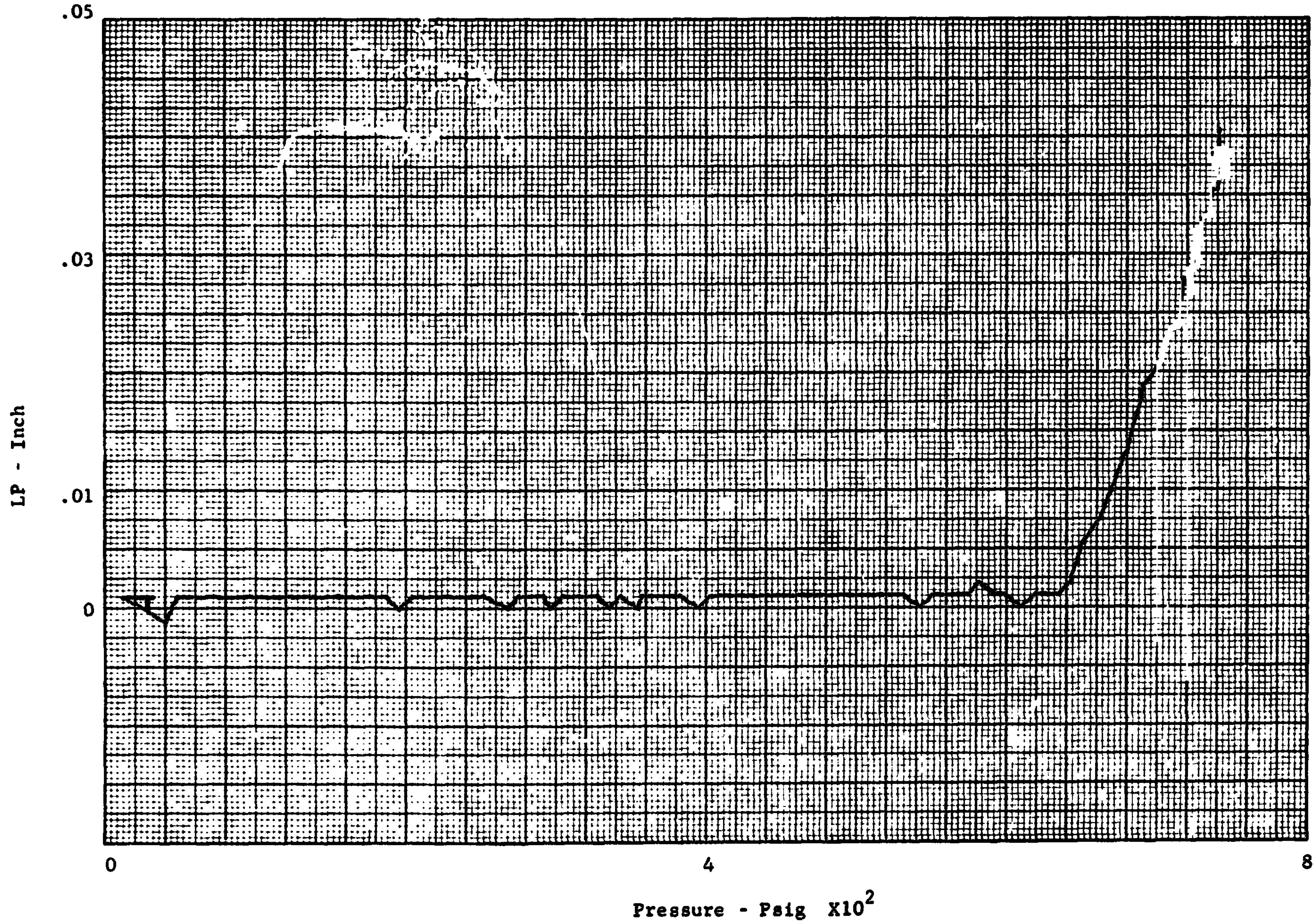
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 23
PLOT RATE 30 SPS



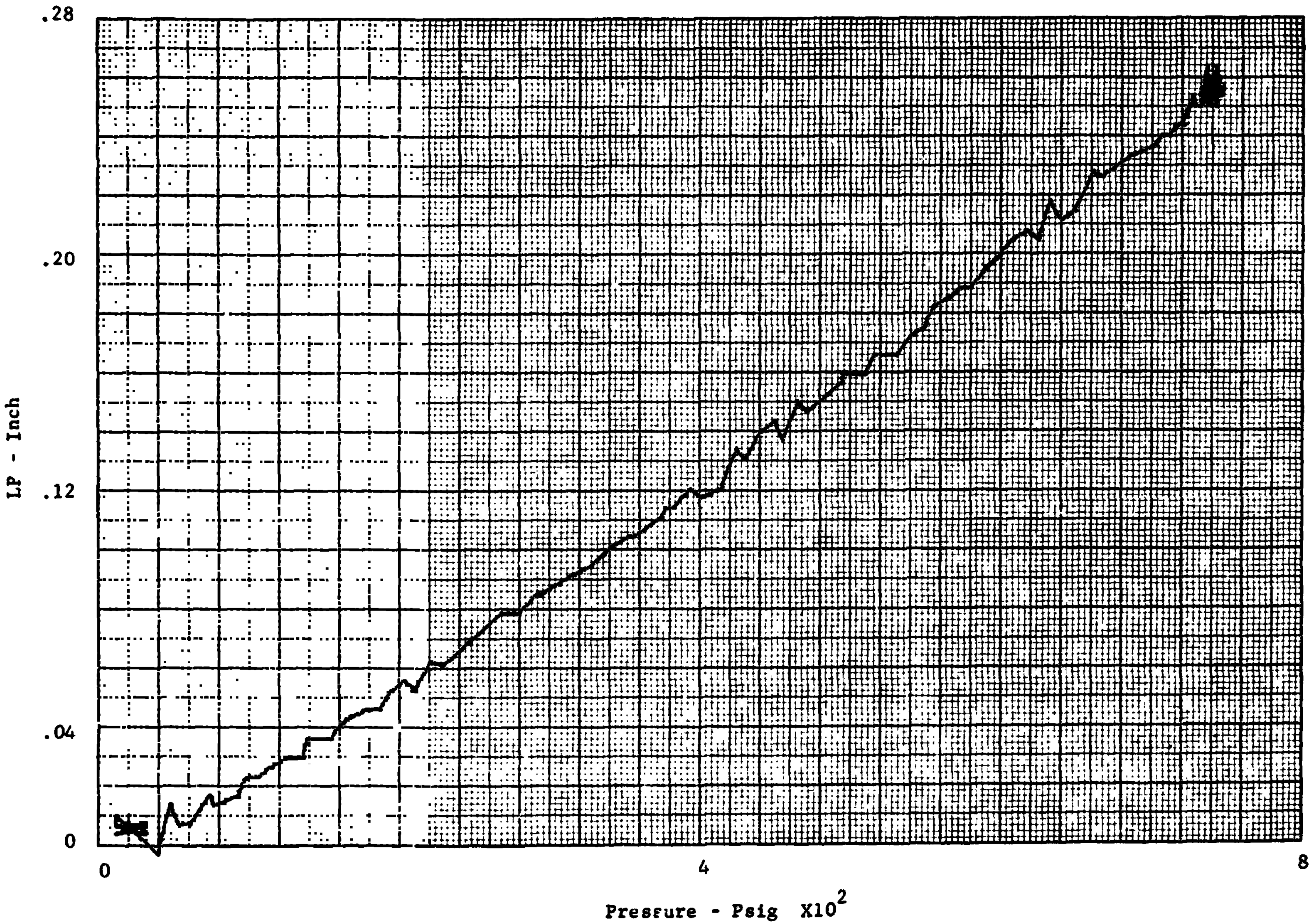
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS STRAIN 24
PLOT RATE 30 SPS



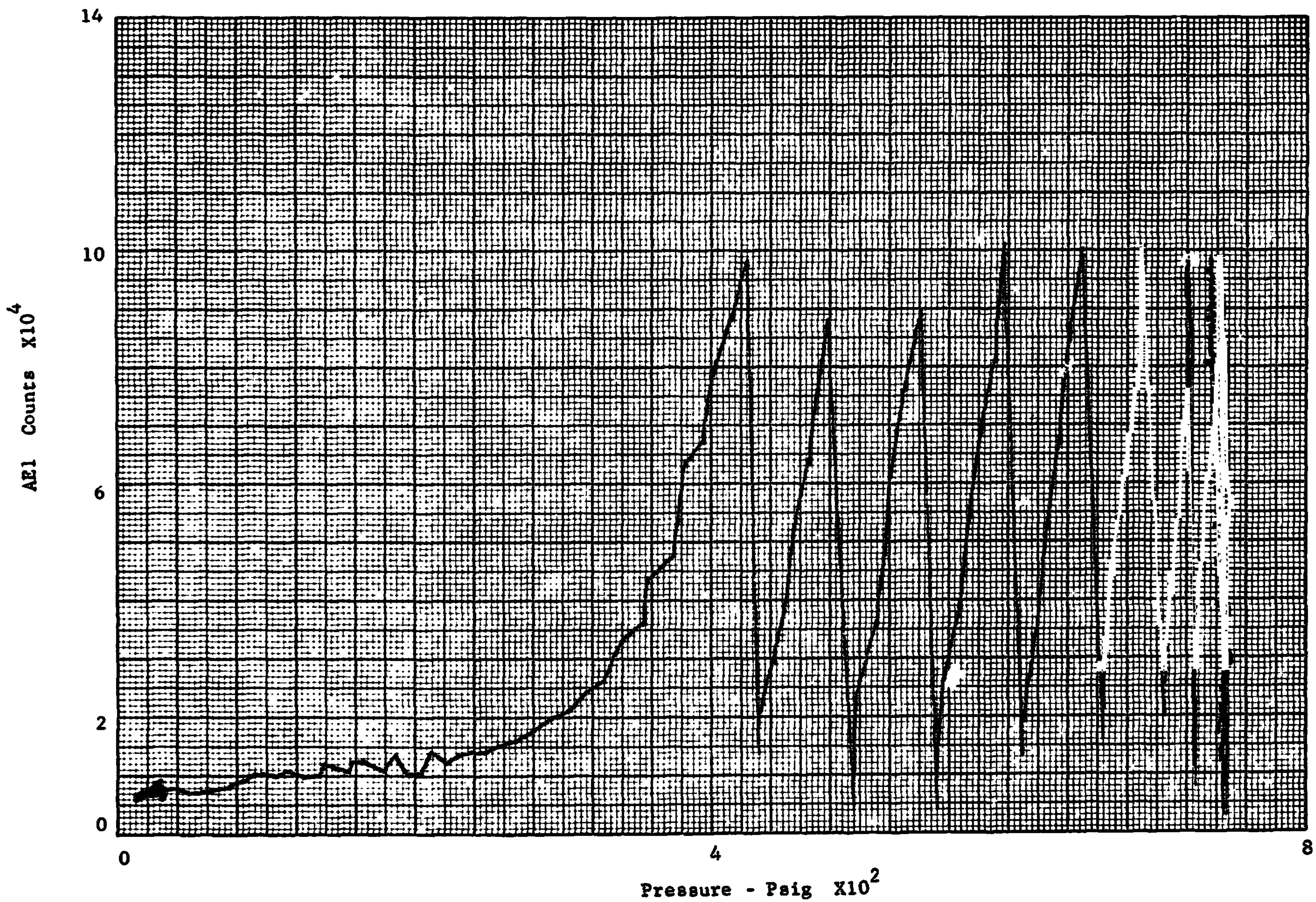
JPL 50 " CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS LP1
PLOT RATE 30 SPS



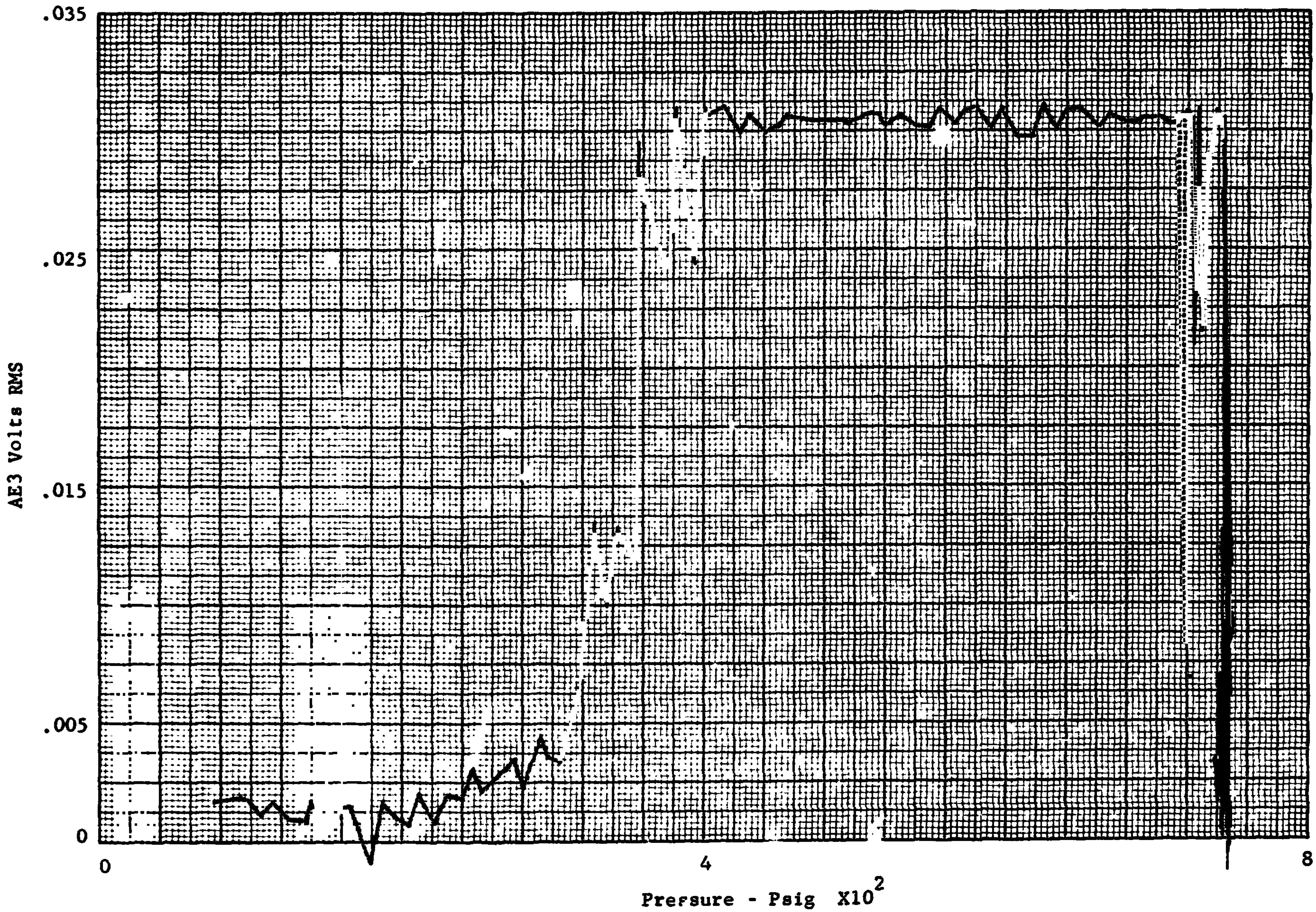
JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS LP2
PLOT RATE 30 SPS



JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS AE1
PLOT RATE 30 SPS



JPL 50" CHAMBER PROOF TEST JPL001
RANGE ROUND NO. ST3230
DATE TESTED 08-27-75
PRESSURE VS AE3
PLOT RATE 30 SPS



Volumetric Expansion for JPL, 60" Dia. [illegible]

50% Proof

	Pressure (psig)	Volume Change (in³)
1.	0	0
2.	48.9	231.91
3.	103.5	476.08
4.	163.7	720.15
5.	223.0	9[illegible].27
6.	2[illegible]0.6	12[illegible]8.39
7.	370.7	1452.[illegible]1

Proof

1.	0	0
2.	43.[illegible]	24[illegible].12
3.	95.[illegible]	488.27
4.	150.[illegible]	732.36
5.	203.[illegible]	976.[illegible]
6.	262.7	12[illegible].60
7.	322.5	146[illegible].72
8.	384.[illegible]	17[illegible].38
9.	449.5	1952.76
10.	516.4	2197.68
11.	584.9	2441.20
12.	660.1	2685.32
13.	743.0	2929.44